THE

ONDON SCIENCE CLASS-BOOKS

EDITED BY

G. CAREY FOSTER. F.R.S.

AND

PHILIP MAGNUS. B.Sc. B.A.

LONGMANS 17 26 PATER NOSTER ROW

PRACTICAL PHYSICS.

MOLECULAR PHYSICS & SOUND

BY

FREDERICK GUTHRIE. PH.D. &c.

THE

LONDON SCIENCE CLASS-BOOKS.

EDITED BY

G. CAREY FOSTER, F.R.S.

Professor of Physics in University College, London;

AND BY

PHILIP MAGNUS, B.Sc. B.A.

Director and Secretary of the City and Guilds of London Technical Institute.

'In this series, each class-book, while thoroughly elementary in character, is contributed by an eminent specialist in the department to which it relates. In each of the manuals the results of the most recent research are embodied, while at the same time the style of exposition is clear and simple, and care is taken to furnish a complete definition of rudimentary principles before taking the pupil further. A valuable feature of all the books is the number and accuracy of the illustrative diagrams they contain.'

SCOTSMAN.

'If we may judge by the volumes we have read, this series ought to be a decided success. The price is low, the subjects are well chosen, and the writers are well known as authorities in their respective subjects and as teachers of experience. It is intended that the works comprised in the series shall be composed with special reference to their use in school teaching; but at the same time the information contained in them is designed to be of such a character as to render them suitable for more advanced students.'

ACADEMY.

ASTRONOMY. By ROBERT STAWELL BALL, LL.D. F.R.S. Andrews Prof. of Astron. in the Univ. of Dublin, and Royal Astronomer, Ireland. With 41 Diagrams. Price 1*s*. 6*d*.

BOTANY, Outlines of Morphology and Physiology. By W. R. MCNAB, M.D. Professor of Botany, Royal College of Science for Ireland. With 42 Diagrams. Price 1*s*. 6*d*.

BOTANY, Outlines of the Classification of Plants. By W. R. MCNAB, M.D. Professor of Botany, Royal College of Science for Ireland. With 118 Diagrams. Price 1*s*. 6*d*.

GEOMETRY, CONGRUENT FIGURES. By O. HENRICI, Ph.D. F.R.S. Professor of Mathematics, University College, London. With 141 Diagrams. Price 1*s*. 6*d*.

HYDROSTATICS and PNEUMATICS. By PHILIP MAGNUS, B.Sc. B.A. Author of 'Lessons in Elementary Mechanics,' Joint-Editor of the Series. With 79 Diagrams. Price 1*s*. 6*d*. (To be had also *with Answers*, price 2*s*.)

*** The Worked Solutions of the Problems. Price 2*s*.

The LAWS of HEALTH. By W. H. CORFIELD M.A. M.D. F.R.C.P. Prof. of Hygiene and Public Health, Univ. Coll. Lond. Medical Officer of Health for St. George's, Hanover Square. With 22 Illustrations. Price 1*s*. 6*d*.

MECHANICS. By ROBERT STAWELL BALL, LL.D. F.R.S. Andrews Prof. of Astron. in the Univ. of Dublin, and Royal Astronomer, Ireland. With 89 Diagrams. Price 1*s*. 6*d*.

MOLECULAR PHYSICS AND SOUND. By FREDERICK GUTHRIE, Ph.D. F.R.S. Professor of Physics, Royal School of Mines. With 91 Diagrams. Price 1*s*. 6*d*.

THERMODYNAMICS. By RICHARD WORMELL, M.A. D.Sc. Head Master of the Middle-Class Corporation School, London. With 41 Diagrams. Price 1*s.* 6*d.*

ZOOLOGY of the INVERTEBRATE ANIMALS. By ALEXANDER MCALISTER, M.D. Professor of Zoology, University of Dublin. With 59 Diagrams. Price 1*s.* 6*d.*

ZOOLOGY of the VERTEBRATE ANIMALS. By ALEXANDER MCALISTER, M.D. Professor of Zoology, University of Dublin. With 77 Diagrams. Price 1*s.* 6*d.*

'Dr. MACALISTER'S manuals are models of what elementary treatises should be and they deserve to become general favourites, not only in schools, but in the universities also. The thanks of the public are due both to the Author and the publishers for having supplied such excellent class-books at so low a price.' SATURDAY REVIEW.

Tenth Edition, in fcp. 8vo. with 124 Woodcuts, price 3*s.* 6*d.*

LESSONS IN ELEMENTARY MECHANICS,

INTRODUCTORY TO THE STUDY OF PHYSICAL SCIENCE.

DESIGNED FOR THE USE OF SCHOOLS AND OF CANDIDATES FOR THE LONDON MATRICULATION AND OTHER EXAMINATIONS, CONTAINING SOLUTIONS OF MATRICULATION QUESTIONS FROM 1869 TO 1881.

By PHILIP MAGNUS, B.Sc. B.A.

Director of the City and Guilds of London Institute.

'A simple, easy, and very pleasant introduction to the study of physical science.' STANDARD.

'The explanations of the Sections are lucid. . . . The lessons meet both teachers' and students' requirements as an excellent exposition of the elements of mechanics.' ARCHITECT.

'We are glad to recommend Mr. MAGNUS'S lessons as coming up to the standard proposed by the Author for an elementary work at once easy enough for a beginner, and at the same time affording a trustworthy basis for the subsequent work of the student.' EDUCATIONAL TIMES.

'The style is lucid, the solved exercises carefully chosen, the work compact. . . . What we consider to be higher praise, is that we believe it to contain nothing that the student will have to unlearn in a subsequent portion of his career. We can recommend it as a trustworthy introduction to more advanced text-books.' NATURE.

'Preparation for examination in elementary mechanics requires a thorough grounding in the principles, and at least as much exercise in their application as is found neccessary in arithmetic and algebra. Mr. MAGNUS'S book seems admirably adapted to furnish these two requirements. The order is scientifically logical, and appears to possess advantages in teaching. The principles are lucidly explained and illustrated.' SCHOOLMASTER.

THE LONDON SCIENCE CLASS-BOOKS

ELEMENTARY SERIES

EDITED BY

PROF. G. C. FOSTER, F.R.S. AND PHILIP MAGNUS, B.Sc. B.A.

PRACTICAL PHYSICS

MOLECULAR PHYSICS & SOUND

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET

PRACTICAL PHYSICS

MOLECULAR PHYSICS & SOUND

BY

FREDERICK GUTHRIE, PH.D. F.R.SS. L. & E.

PROFESSOR OF PHYSICS IN THE ROYAL SCHOOL OF MINES
AND NORMAL SCHOOL OF SCIENCE, LONDON

LONDON
LONGMANS, GREEN, AND CO.
1885

EDITORS' PREFACE.

NOTWITHSTANDING the large number of scientific works which have been published within the last few years, it is very generally acknowledged by those who are practically engaged in Education, whether as Teachers or as Examiners, that there is still a want of Books adapted for school purposes upon several important branches of Science. The present SERIES will aim at supplying this deficiency. The works comprised in the SERIES will all be composed with special reference to their use in school-teaching; but, at the same time, particular attention will be given to making the information contained in them trustworthy and accurate, and to presenting it in such a way that it may serve as a basis for more advanced study.

In conformity with the special object of the Series, the attempt will be made in all cases to bring out the educational value which properly belongs to the study of any branch of Science, by not merely treating of its acquired results, but by explaining as fully as possible

the nature of the methods of inquiry and reasoning by which these results have been obtained. Consequently, although the treatment of each subject will be strictly elementary, the fundamental facts will be stated and discussed with the fulness needed to place their scientific significance in a clear light, and to show the relation in which they stand to the general conclusions of Science.

In order to ensure the efficient carrying-out of the general scheme indicated above, the Editors have endeavoured to obtain the co-operation, as Authors of the several treatises, of men who combine special knowledge of the subjects on which they write with practical experience in Teaching.

The volumes of the Series will be published, if possible, at a uniform price of 1*s.* 6*d.* It is intended that eventually each of the chief branches of Science shall be represented by one or more volumes.

G. C. F.
P. M.

AUTHOR'S PREFACE.

I HOPE that the following outlines of Practical Physics, including, I. Molecular Physics, Waves, and Sound; II. Heat and Light; III. Electricity and Magnetism, may be of use to those Teachers and Students who wish to give or to get more than a mere word-knowledge of the matter. Such knowledge alone no more gives its owner a right to be reckoned a Physicist than does a knowledge of sound and harmony entitle him to be called a Musician, or a knowledge of perspective and colour to the name of Artist.

It has been the strong wish and effort of some few Physicists of late years to bring practical work into their teaching, and thus to do for Physics what has been for so long done for Chemistry with great gain. For it seems that knowledge got by the head alone is often very fleeting: whereas when head and hand learn together, the power of keeping is strengthened. And we look upon such practical teaching as good, not only because it is the only way to forge the link by which man is bound to nature, but also because it forms the one discipline of truth in the ways of matter.

FREDERICK GUTHRIE.

LONDON, 1885,

CONTENTS.

COHESION OF SOLIDS.

COHESION OF LIQUIDS AND GASES.

VOLUME-ELASTICITY OF SOLIDS, LIQUIDS, AND GASES.

COHESION OF LIQUIDS AFFECTED BY ADHESION TO SOLIDS.

COHESION OF SOLIDS AFFECTED BY ADHESION TO LIQUIDS.—ABSORPTION OF GASES.—DIFFUSION.

DENSITY.—SPECIFIC GRAVITY.

VORTEX MOTION.

WAVES.

ORIGINS OF SOUND WAVES.

THE GAS WAVE.

LONGITUDINAL VIBRATIONS IN LIQUIDS AND SOLIDS.

APPENDIX.

PRACTICAL PHYSICS.

PART I.

MOLECULAR PHYSICS AND SOUND.

COHESION OF SOLIDS.

§ 1. **Hardness. Form-elasticity.**—The pressure required to alter the relative positions of two contiguous parts of a body measures its hardness. As this pressure is greater with greater surfaces of contact, some unit of surface must be fixed upon. The term hardness is generally applied loosely to difficulty of fracture. The following remarks may show that our speech and ideas in regard to hardness are deficient in precision. Glass is said to be harder than lead, yet a glass cup is more easily broken than a leaden one—more easily broken, though not so easily bent. Hard bodies are always elastic; elastic bodies are not necessarily hard, nor are they necessarily brittle, nor are soft bodies necessarily plastic. Toughness seems to imply a resistance to change of form, which resistance increases more rapidly than the displacement; thus, while a band of vulcanised caoutchouc will be extended to a degree proportional to the weight hung at one end, a leathern strap will

not be extended twice as far if the weight on it is doubled. Toughness is generally associated with texture, and stretching causes partial fibration in the line of pull.

The hardness of minerals, stones, and similar bodies, is usually referred to the terms of the following series:

(1) Talc . . .	Silicate of magnesium
(2) Gypsum (selenite) .	Sulphate of calcium
(3) Rock salt . . .	Chloride of sodium
(4) Calc-spar . . .	Carbonate of calcium
(5) Apatite . . .	Phosphate of calcium
(6) Felspar . . .	Silicate of potassium and aluminum
(7) Quartz . . .	Silica
(8) Topaz . . .	Fluosilicate of aluminum
(9) Corundum (sapphire, ruby) . . .	Alumina
(10) Diamond . . .	Crystallised carbon

Each of these scratches all of those above it, and is scratched by those below. Thus, if a body under examination is found to scratch felspar, but to be scratched by quartz, its hardness is said to be between 6 and 7. This method of comparison is somewhat vague; it is usually applied by rubbing an edge or point of one body on a surface of the other, and although of course the common surface of the two is identical, the surfaces are not equally supported by surrounding matter. On rubbing together two equal spheres of iron and lead, the latter metal is rubbed off; on pressing them together, the lead is indented, showing that its cohesion

or hardness is less than that of the iron. Nevertheless, a leaden bullet will pierce an iron plate, and a rapidly revolving disc of iron will cut the hardest steel. Also if a glass tube be broken in the middle, the jagged edge can be broken off by the smooth tube, and the smooth tube can be scratched by the ragged edge.

§ 2. The cohesion of metals is usually measured as tenacity, that is, by finding the maximum weight which wires of a given thickness will carry. The drawing of a wire through a stock tends, however, to render the metal fibrous, and to give it a skin which is more tenacious even than the interior. Since the surface varies with the diameter, and the sectional area with the square of the diameter, two wires, each of sectional area *a*, will support more than one of sectional area 2*a*, because the sum of the circumferences or skin-rings of the two is greater than the skin-ring of the larger wire. Thus, a drawn steel rod of 1 meter in length will not support so much as the same steel drawn into a wire 1,000 meters long, cut up into 1,000 lengths of 1 meter each, and forming a bundle. The tenacity of the skin can be reduced by annealing (heating and slow cooling), but it is here, as always, impossible to get the solid body perfectly homogeneous. Some experimental measure may be got of the tenacity, by fastening one end of the wire to a spring balance rigidly fixed and the other to a pianoforte peg, and turning the peg till the wire breaks. After one wire has been broken, a second is taken, and the index is more narrowly watched, or made self-registering.

§ 3. Wires which are pulled by forces insufficient

to break them are elongated, and return after the withdrawal of the stretching force more or less completely and rapidly (from a second to several days) to their original lengths. To prove that within the limits of such elasticity the extension is proportional to the stretching force, two points or lines are marked on the wire, which should for this purpose be two or three yards long, the marks being an inch or two from each end. The wire is hung vertically, is gently weighted, and while so strained it is annealed by passing along it the flame of an air-gas burner. If the metal will bear it, each part is made red-hot in succession. This removes kinks, and makes the wire absolutely straight. The distance of the marks apart is then measured by a cathetometer, and the distance is again measured when the stretching weight is changed. It may be assumed that all parts of the wire are stretched equally; it may also be assumed that the volume of the metal remains approximately unchanged, so that if the elongation is such that the length m becomes n, the original diameter d becomes $d\sqrt{\frac{m}{n}}$. Besides this true elasticity, whereby wires recover their length, they, when stretched nearly to breaking, become permanently elongated. A thin copper wire may be cautiously stretched between the hands a quarter of its length longer, and every wire will bear more if loaded gradually than if loaded quickly, even though the latter operation be quite continuous.

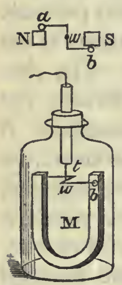
§ 4. **Elasticity.**—Bodies differ from one another in regard to elasticity (1) as to the pressure required to produce a given deformation, and (2) as to the reco-

very of their original form after deformation. Hard steel and glass, for example, recover their form very perfectly even after great deformation ; while in lead the recovery is complete only when the deformation has been very small. The pressure necessary to cause and maintain a given deformation may be called degree of elasticity. Vulcanised caoutchouc is nearly perfectly elastic for small displacements, but its elasticity is not so strong as that of glass, steel, or ivory. The elasticities of wires and rods can of course be directly, but only roughly, measured by the elongation method. If a rectangular rod be bent from the straight to an arc, the outer face is elongated and the inner crushed together, and accordingly there is a certain surface which is neither stretched nor crushed. When a rod or wire, which may be supposed to be vertical and fastened above, is twisted, every series of particles which to begin with lay in a horizontal plane still do so, but the plane itself is raised. Particles which lay in a vertical line now lie in a spiral, and contiguous vertical lines of particles must slide over one another. The rod or wire shortens, and there is on the whole an intermolecular motion proportional to the pressure maintaining the twist or torsion. And this fact furnishes the best method of proving that with the same substance the elasticity, or effort to regain original shape, varies with the angle of torsion or deformation.

§ 5. A horseshoe magnet, M, is set up under a bell-jar in a vertical plane (fig. 1). Two pieces of cardboard or mica are stuck on the poles on alternate sides. Two little equal soft-iron bullets are soldered to the ends of a stiff brass wire, *w*, which is then bent

twice at right angles in a plane, so that when the centre of the wire is in the axis of the jar the bullets may rest on the cardboard. One end of the wire which is being experimented on is soldered to the middle of the brass wire, the other passes through a narrow glass tube, t, at the upper end of which it is fastened by a drop of sealing-wax. The tube passes stiffly through a cork in the mouth of the bell-jar and carries an index, which passes over a scale of angles on the cork. A horse-shoe keeper is placed on the magnet, and the tube is turned till the balls are in contact with the cardboard. The keeper is then removed, and the balls are attracted to the poles. Gradually turn the tube in the cork till separation ensues; read off the angle of torsion, α_1, measure the length, l_1, of the wire from the glass tube to the brass wire. Soften now the wax which holds the wire in the tube and alter the length of the free wire to l_2, pushing the tube through the cork till the balls rest exactly where they did before. Turn as before till separation ensues. The new angle being α_2, it is found that

FIG. 1.

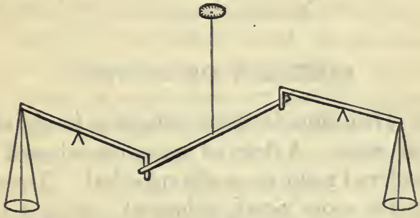


$$\frac{l_1}{l_2} = \frac{\alpha_1}{\alpha_2}.$$

Or if the wire be twice as long, the upper end must be twisted through twice the angle in order to give a given thrust at the lower end. One may derive the same fact by reasoning only, in the following way. Suppose a pair of tangentially acting forces, $p\ p$,

applied at given arms, a a, to the middle of a wire of length l, fixed at the top but hanging free below, to cause an angular twist of α there, and therefore also at the bottom of the wire. Clamp the wire in the middle, and the frictional resistance of the clamp will perform the same office as the pressures p and p. Twist now the bottom end also with pressures p and p, also acting at arms a and a. They will turn the end round through an angle α, and if the clamp be now loosened, the wire will be found to be in equilibrium. So that, applied at the end, a pair of twisting forces (a couple) will give a torsion angle 2α if they give an angle α when applied in the middle

FIG. 2.



§ 6. To show that, with the same length of wire, the pressure is proportional to the angular displacement, the wire can be fastened as in fig. 2. Its cross-arm at the bottom rests against the two vertical arms of two balanced levers provided with scale-pans. If the upper end of the wire receives a given twist, the lower end is kept in its place by altering the weights in the scale-pans. With double the twist the weights must be doubled, and so on.

§ 7. By far the best proof of this relationship,

although an indirect one, is the isochronism of a torsion pendulum. A cannon-ball is bored through the middle; a steel wire is fastened to it with lead, the other end being supported on a strong stand; the ball is twisted round three or four times, and let go. It may keep its motion forwards and backwards for forty-eight hours. Whatever may be its angular amplitude of swing, its period is very nearly identical. This can only be the case if the angle of displacement is proportional to the pressure of displacement—a condition approximately fulfilled by the common pendulum only when the arc traversed is so small as to be sensibly equal to the corresponding chord.

COHESION OF LIQUIDS.

§ 8. That liquids have cohesion is shown in a variety of ways. A drop of water on a board strewn with powdered resin is nearly spherical. The smaller the drop the more nearly spherical. So is a drop of water on a sheet of paraffin, or a drop of mercury upon almost every substance. The spherical is the form in which the mean distance of all parts from the centre of mass is the least. It is the most compact form for a given mass. This shows that cohesion moulds the drop to the spherical form. This result is very elegantly shown by making such a mixture of alcohol and water as has the same specific gravity as olive oil. Alcohol being lighter and water heavier than oil, alcohol is added to water in which there are a few drops of oil

until the latter just float when the mixture has cooled to the ordinary temperature. Fresh oil is then, by means of a pipette, poured into the middle of the mixture. Spherical globes several inches in diameter can thus be formed.

§ 9. One of the best, as it is one of the simplest, methods of measuring the cohesion of liquids is to suspend a flat, round plate of glass, thoroughly cleaned, from one pan of a balance, and to counterpoise it; the surface of the glass being adjusted so as to be exactly level, bring under it a dish of water, and lift and support the dish till the bottom of the plate is in contact, without air bubbles, with the water, taking care not to wet the top; load gradually the other pan till the plate is torn away. It does not matter what the plate is made of, provided it is wet by water; the same force is required, and this is the force required to tear asunder a given surface of water from the neighbouring lower surface. It is not the separation of water from glass, because the lower surface of the glass remains completely wetted. A good way of hanging the glass is to heat it and fasten by wax three threads to its upper surface. These are tied together a few inches above the plate, and fastened to a single thread which is fastened to the pan of a balance. On wiping the glass dry and replacing the water by alcohol, a less force is found to be necessary.

§ 10. A beautiful way of showing that water has cohesion is to let a smooth vertical column of water, not flowing too fast, fall fair upon a small round cup or horizontal disc. The water is thrown off horizontally, but is not scattered as spray; it draws itself

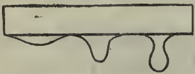
together, forming a sort of film water-bottle of graceful form. Mercury acts in a similar manner.

§ 11. Another method of showing liquid cohesion is to close one end of a wide glass tube, bend it in the middle, draw out the other end, and tie over it a piece of black caoutchouc tubing. The tube (fig. 3) is nearly filled with water, which is then boiled uniformly till about a quarter has been boiled off. The caoutchouc is then pinched between the fingers near the glass, and the flame is withdrawn. In a few seconds the fingers may be taken away, and the narrow part of the neck may be sealed off over the flame. The pressure of the air closes the caoutchouc, and assists the closing of the glass. On cautiously turning the tube over, the liquid stands as in the figure. Accordingly, as the water-column does not break, it must have cohesion. A smart rap on the table breaks the column, and the water then stands at the same height in both limbs.

FIG. 3.

§ 12. The cohesion of liquids can be most accurately measured and compared by determining the degree to which such cohesion has affected the size of a fallen drop. What is here meant by a drop is a mass of liquid (fig. 4) which has wetted a solid and which has accumulated on the solid until its cohesion has been overcome by its own weight. It then falls, its size depending very little upon the nature of the solid from which it falls, but very much upon the rate at which it drops,

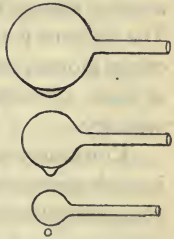
FIG. 4.



upon the shape of the surface from which it drops, upon the density of the liquid, and upon its cohesion. To show how much depends upon rate, other things being the same, let water flow from a siphon provided with a stop-cock upon a glass sphere (a round glass flask) so that the drops succeed one another at the rate of 2 per second. Catch 100 in a weighed flask and weigh. Let now the drops succeed one another at the rate of 1 in 10″, or twenty times as slow as before; catch 100 and weigh. The first hundred will weigh far more than the last: about one-third as much again. And of course every drop of the quick delivery bears this proportion to every drop of the slow.

§ 13. Again, other things being the same, the flatter the surface the larger the drop. Fasten (fig. 5) three round glass flasks one above the other in order of magnitude, and put a little muslin cap on each. Let water flow from a tube upon the upper one. Drops will fall from this to the next lower, from this to the third, and from the third into a basin. The same quantity of water drops in the same time from each sphere, or if anything a little less from the lower spheres on account of evaporation. And yet the drops succeed one another far faster from the lower than from the upper spheres. The largest drops are those which fall from a flat surface. The effects of density and cohesion are opposed to each other, but experiment shows that increase in specific gravity, which by itself always tends to diminish drop

FIG. 5.



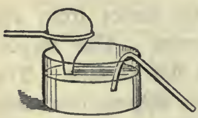
size, may be more than counterbalanced by increased cohesion. Thus if the radius of a sphere of platinum be 1·14 centimeters, and various liquids be made to drop from it at the rate of one drop in every 2″, at a temperature of 26° C., the actual volumes in cubic centimeters of 1 drop of each liquid are as follows :

Water	0·148
Glycerine	0·103
Mercury	0·058
Benzol	0·055
Oil of Turpentine	0·050
Alcohol	0·049
(glacial) Acetic acid	0·043

The mercury is made to touch the platinum by rubbing the surface of the platinum with a little mercury in which a minute fragment of sodium has been dissolved. The sodium is rubbed into the mercury in a dry porcelain mortar, whereupon the two unite with liberation of heat. The platinum is then washed in fresh clean mercury.

Constancy in delivery is got by using a siphon and inverting into the basin which feeds the siphon a flask containing the same liquid (fig. 6). The level of the liquid never falls sensibly below the neck of the flask if the latter is notched. If the liquid can be had, like water, in any quantity, a more exactly constant level is got by allowing the basin to continually overflow by receiving a succession of drops con-

FIG. 6.



taining a greater supply of liquid than the siphon has to deliver, and by regulating the overflow by laying a square piece of linen with one corner hanging over the edge of the basin. This acts as a siphon of variable capacity. In the case of mercury the linen is replaced by a piece of amalgamed platinum foil.

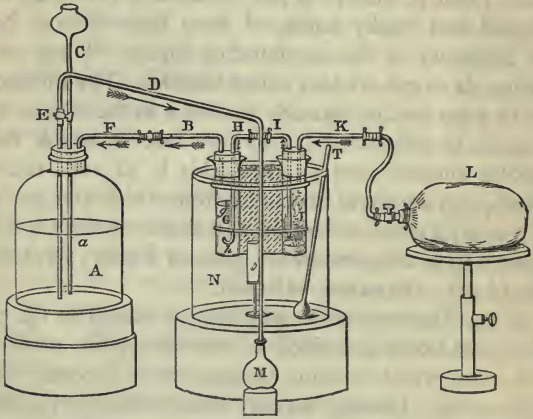
§ 14. **Bubbles.**—The cohesion of liquids also determines the shapes and sizes of bubbles properly so called; that is, masses of gas liberated in the midst of a liquid and finally separated from their sources by the buoyancy of the surrounding liquid. Films enclosing air or gas are also called bubbles. The bubble-size of a gas issuing through an orifice in the middle of a liquid is influenced (1) by the rate at which the bubbles succeed one another (this is of very small effect); (2) nature of the solid from which the gas is delivered; (3) size of orifice and distribution of solid about it; (4) temperature of gas and liquid; (5) tension of gas; (6) nature of liquid.

§ 15. The apparatus employed is shown in fig. 7. The quart bottle A is filled a little above the mark *a* with water, which in some experiments is covered with a film of oil. Through its cork three tubes, C E F, pass absolutely air-tight. The tube C is a simple funnel tube open near to the bottom of A. The tube D also reaches to the bottom of A and acts as a siphon. Its longer limb is narrowed at the end, and delivers its water into the little flask M whose neck bears a mark. The shorter limb of D bears a cock E to regulate its discharge. The third tube F, which opens immediately under the cork of A, is fastened by a caoutchouc joint to the tube B. In this joint, and pressing

the ends of both tubes, is a compact mass of cotton wool. B passes through the cork of the little test-tube G, which is divided into millimeters and contains the liquid through which the bubbles are to pass.

Through the cork of G another tube H is passed, which is bent round near the lower end *h* so as to open upwards, and is beneath the surface of the liquid in G.

FIG. 7.



H is connected by a caoutchouc joint with I, which passes nearly to the bottom of a second little test-tube J. The tube J contains a few drops of the liquid which is in G, and the space between I and the sides of J is filled with cotton wool moistened with the same liquid. The last tube K, which opens immediately under the cork of J, is either open to the air or connected with a gas bag containing the gas under examination, or

fastened to a chloride of calcium tube according to the requirements of the experiment. In some experiments the little tubes G and J are surrounded with water contained in the vessel N. A thermometer T is placed in the water of N.

The apparatus is used as follows. B and F being disconnected, the bottle A is nearly filled through C. The end of F is closed by the finger, and, the stop-cock E being opened, the siphon D is filled once for all by applying the mouth to its longer end. E being then closed, the tube G is filled up to the required mark with the liquid which is to serve as a bubble medium. The cotton wool in J is moistened with the same liquid. All the joints are made fast, and the tube K is connected with the gas bag L. On turning the stop-cock E, water flows through the siphon D into the flask M. To supply its place, gas must enter by F, that is, gas must bubble through the liquid in G. Before entering G it becomes saturated with the vapour of the same liquid in J. If all the joints are tight, it follows that the volume of water entering M is equal to the volume of gas which bubbles through the liquid in G. It is a sufficient test of the tightness of all the joints (as far as H) to run off a little water by D so as to bring a bubble or two of the gas through *h* and to allow the apparatus to rest. If the tube H remains full of air to its extremity for a quarter of an hour, the apparatus may be considered as air-tight. A metronome is adjusted to beat to the required time. M is removed and emptied. E is turned till the bubbles passing through the liquid in G keep time with the beats of the metronome. This rate is maintained till the liquid in A sinks

to *a*. The flask M is then put in its place, and from that instant the bubbles passing through G are counted. When M is filled exactly up to the mark the experiment is finished. The proximity between M and G enables the eye to count the bubbles and to watch without difficulty, at the same time, the rise of the liquid in M. The contents of M, divided by the number of bubbles, gives the mean volume of a single bubble. The use of the cotton wool in the joint between B and F is to check the flow of gas through the apparatus. When this plug is absent, the considerable volume of gas in the upper part of A, being in direct communication with G, causes by its elasticity an irregular delivery of bubbles through G. Of course as M is filled, the level of the liquid in A falls. The difference between the limbs of the siphon D is diminished; the flow through D is retarded, and the bubbles follow one another more slowly; this, however, makes exceedingly little or no difference in the size of the bubbles.

§ 16. The radii of the tubes being shown in column (1), the volumes of the air bubbles delivered from the tubes at the rate of 1 bubble in 2″ are shown in column (2). The liquid medium is water.

(1)	(2)
0·1428	0·035
0·4595	0·149
0·6035	0·152
1·4099	0·178
1·7607	0·244
2·0998	0·319

§ 17. The combined effect of the cohesion and

specific gravity of the liquid in determining the bubble-size, is measured by altering the liquid while other circumstances are maintained the same. In the following table are given in cubic centimetres the bubble-sizes of air passing through various liquids.

Mercury	0·4120
Glycerine	0·1145
Water	0·0860
Butyric acid	0·0582
Acetic acid	0·0572
Alcohol	0·0480
Benzol	0·0480
Oil of Turpentine	0·0453
Acetic ether	0·0372

In determinations of this last kind the gas bag L is replaced by a chloride of calcium tube. The cotton wool of J is saturated with the liquid under examination in G, so that the bubbling gas is dry air already saturated with the vapour of the liquid through which it has subsequently to bubble. It is clear that if the air so charged were to come into contact with the water in A, the vapour would dissolve in the water, while the air would become moist. A difference in volume would be thereby occasioned, according to the difference of the tension of the vapour of the liquid in G and J on the one hand, and that of water on the other. To avoid this source of error, the vessel A is filled with mercury; and after each experiment the vessel A is completely refilled with mercury, so as to expel the vapour of the liquid used in the previous experiment. The mercury is then run off at D until

it falls in A, nearly to the mark *a*. The liquid under examination in G should have a height above *h* inversely as its specific gravity. This is easily effected by means of the graduation of the tube G. By this means the pressure on the gas as it issues from *h* is the same in all the experiments. The vessels A, G, and J are all sunk in the same trough of water, so that the volume of the air undergoes no alteration from temperature, either during or after its passage through G. When the growth-time of the bubbles has been brought exactly to the pre-determined value (say 2″), and the mercury in A has sunk to *a*, a graduated burette is brought under the siphon D, and kept there while 100 bubbles pass through G.

§ 18. The size of an air bubble formed under given conditions in a mixture of two liquids, A and B, is a mean between its size through A and through B. And a very accurate estimate of the relative quantities of the two constituents of a mixture can be got if we know the bubble size in each constituent.

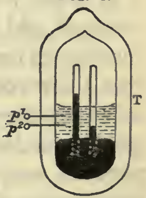
§ 19. **Cohesion of Gases. Viscosity.**—Although a gaseous mass will preserve neither its shape nor its volume unless enclosed by solid or liquid walls, and is, therefore, destitute of that cohesion which is represented by hardness and form-elasticity, it offers, according to its nature, a variable resistance to bodies passing through it. Now, as such resistance in the case of solids and liquids is obviously and directly associated with their hardness, we may here mention the chief direct experiments on the viscosity of gases. This has been most accurately determined in a direct manner by pendulum experiments. A pendulum is made

to swing, beginning with a given arc, in a chamber which can be filled with any gas. By raising or lowering a mercury valve, a constant tension of the gas in the chamber can be obtained. The time occupied by the pendulum in performing a given number of oscillations is noted. A more exact method is to place timed chronometers under bell-jars containing various gases, and also in vacuo.

VOLUME-ELASTICITY OF SOLIDS, LIQUIDS, AND GASES.

§ 20. No direct and exact measurements have been made of the compressibility of solids. For sensible compression such enormous pressures are required, that at present exact measurements are wanting. And even with most liquids the compressibility is so small, even by great pressures, that special 'piezometers' are used. One form of piezometer, which can be made without much difficulty, is shown in fig. 8. A very stout glass tube, T, is closed at the bottom, and about half-way up in its side two platinum wires, p_1 p_2, are fused through the glass. Some mercury is poured in, and then two tubes, one containing air and the other the liquid under examination, both being closed at the top and open below, are introduced, so as to stand in the mercury. Finally, a little dilute sulphuric acid is introduced, so as to cover

FIG. 8.



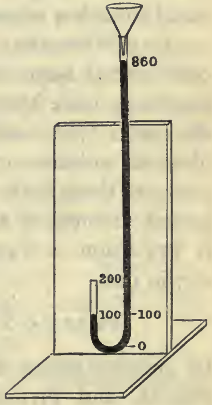
the platinum wires, and the tube is then hermetically sealed. On connecting p_1 and p_2 with the poles of a two-cell platino-zinc battery, the water is decomposed into its two elements, which, not being able to escape, exert a greater and greater pressure on the sulphuric acid, and thence on the mercury surface, and so compress the air in the one tube and the liquid in the other. As we shall see in § 22, the volume of a given mass of air is inversely proportional to the pressure upon it. Hence, if the volume of air is halved by the pressure thus generated, we know that the pressure is doubled, that is, instead of being exposed to one atmosphere, it is exposed now to two, and so on. It is not safe to generate a pressure of more than four or five atmospheres; and it is dangerous to allow the platinum to be exposed above the liquid, for the clean platinum may determine the recombination of the elements of water with great violence.

§ 21. **Elasticity of Gases: Relation between Volume and Pressure.**—It appears that gases, vapours, and liquids are continuous in their elastic properties. The gases most difficult to condense are hydrogen, nitrogen, and oxygen, and a few compound gases. The three gases named follow very nearly the generalisation that their volume varies inversely with the pressure to which they are subjected. Substances which are gaseous under ordinary conditions of temperature and pressure, may, when the pressure is increased or the temperature diminished, become liquids. Such liquefiable gases are often called vapours; and the generalisation which connects vapours and gases is that the nearer a vapour is to liquefaction, either by in-

creased pressure or by diminished temperature, the more does it depart from the generalisation that its volume varies inversely as the pressure upon it.

§ 22. A tube of about $\frac{1}{4}$ in. internal bore, and 4 ft. long, is thoroughly cleaned, and one end is closed and flattened by pressing on it when red hot a piece of flat charcoal; or the edge may be turned so as to form a lip, and a well-fitting cork being driven in, is tied down by thin copper wire, which passes also beneath the lip. The cork is then thickly and smoothly covered with sealing-wax (fig. 9). The tube is then bent so as to form two parallel limbs, of which the shorter, which is the closed end, is about 6 in. long. It is now fastened to an upright support, and a drop or two of mercury is poured into the open end, so as just to cover the bend and shut off the air in the closed limb. Adjust a millimeter scale to both limbs so that the 0 is on a level with the mercury. Suppose the barometer stands at 760 millimeters of mercury at the time of the experiment; and suppose that the top of the closed tube is opposite the 200 millimeter mark: pour mercury into the long limb until the mercury in the short limb stands at 100; the mercury in the longer limb will then be seen to stand at 860, that is, 760 millimeters above the mercury in the shorter limb. The two

FIG. 9.



columns, each 100 mm. long, in the two limbs balance one another. Therefore, in order to halve the volume of the air in the shorter limb, it has had to be pressed by an additional atmosphere. A similar relationship is observed for all pressures. On compressing a gas, it is heated ; and a gas, when heated, tries to expand. If, therefore, mercury is poured suddenly into the longer limb, the air compressed in the shorter limb becomes warm, and by its increased tension balances a longer column than it would when cold. Before finally measuring, the apparatus should be allowed to stand for a few minutes to cool—say thirty minutes.

§ 23. When the observations of gas-volumes extend over several hours during which the barometric pressure may have altered and has perhaps never been the mean (760 mm.), it is convenient to reduce all observed volumes to this mean pressure in order to compare them fairly with one another. Thus the observed volume of a gas to-day when the barometer is 754·2 mm. is 69·22 c.c. The gas would measure at 760 mm.

$$69{\cdot}22 \text{ c.c.} \times \frac{754{\cdot}2}{760} \text{ that is, } 68{\cdot}69 \text{ c.c.}$$

In general terms if H_1, H_2 be the two barometric heights, and v_1, v_2 be the corresponding volumes of the same mass of gas

$$v_2 = v_1 \frac{H_1}{H_2}$$

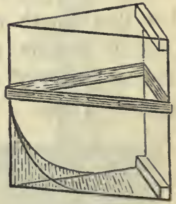
Every mass of matter at rest is of course exercising as much pressure as it supports. The compressed gas is accordingly exercising a pressure, tension or elasticity, equal to the compressing force. There

being the same mass (weight) of air before and after the compression, doubling the pressure, in halving the volume, of course doubles the density.

COHESION OF LIQUIDS AFFECTED BY ADHESION TO SOLIDS.

§ 24. **Capillarity.**—It is found experimentally that the height to which a liquid rises in a cylindrical tube of a solid which it wets, is inversely proportional to the diameter of the tube. More generally expressed, when a tube is partly plunged into a liquid, the difference in height between the inner and the outer liquid is inversely proportional to the diameter of the tube. That this is approximately true is seen at once by binding together two square plates of glass in such a way that they form an angle of about 2° opening. The plates are wedged slightly apart along one edge by two thin bits of cork, and the opposite edges being brought together, a vulcanised caoutchouc band is passed round. On allowing the base of the hollow prism formed by the plates to dip into coloured water, the latter forms between the plates an open curve,

FIG. 10.



called a rectangular hyperbola, such that the vertical height of any point of the curve above the level surface of the water is inversely proportional to the distance of this point from the edge along which the plates

touch each other. For exact measurements and verification of the generalisation above given, some form of cathetometer should be used for the height measurement, while the diameter should be measured indirectly by ascertaining the length of a certain length of a known liquid filling the cavity of the capillary tube.

§ 25. Although round and often uniform in bore, the ordinary capillary thermometer tubes are unsuitable for such experiments on account of the great thickness of the glass. A piece of glass tube is softened and drawn out to about 6 ft. as uniformly as possible. The central part of this is taken as being the most uniform in bore. A little mercury is drawn in, and the thread tube being laid upon a scale, the length of the mercury column at different parts ot the tube is measured. That part of the tube where its length is nearly constant may be employed. Its diameter is determined by weighing one or two feet of it when empty, and again when full of distilled water. Let its weight when empty be 1·4632 gram. Let this length measure 563·2 millimeters, and suppose it weighs 1·4740 when full of distilled water. The cylinder of water 563·2 mm. long weighs 0·0108 gram. Then

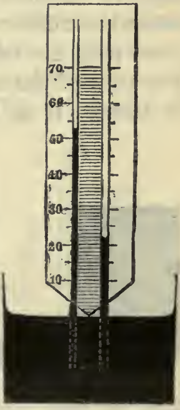
$\pi r^2 \times 563{\cdot}2$ mm. weighs 0·0108 gram.
" measures 0·0108 c. c.
" 10·8 c. mm.
$r = 0{\cdot}0248$ mm.

If the tube be wide, say 5 or 10 mm. in radius, mercury may with advantage be substituted for water.

The result will then have to be divided by the specific gravity of mercury (13·5). But with narrow tubes, the film of air between the mercury and the glass introduces a sensible error.

The diameters of two tubes having been thus determined, they may be laid side by side on to a freshly varnished paper millimeter scale in such a way that their ends project below. The scale is cut away to a point between the tubes at the 0 line. The heights are then at once read off. Very exact comparative measurements can be got in this way of the capillary heights in different tubes of the same liquid. For absolute measurements the tubes must be perfectly vertical, as the downward pressure of the liquid column depends upon the height of the top of the capillary column above the level in the reservoir, and not upon the absolute length of the column.

FIG. 11.

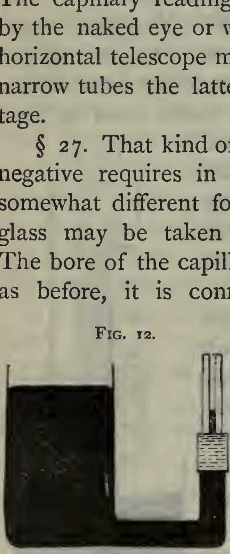


§ 26. If many capillary heights have to be determined, a steel millimeter scale may (fig. 11) be filed to a sharp point at the 0 line, taking care that nothing is filed off. Longitudinal scratches are made along the scale for the tubes to rest on, and they are fastened to the scale by a little soft wax or varnish. The scale is then clamped vertically. This is effected by comparing one of its edges with two plumb lines which, as seen from that edge, appear under an angle of about 90°. The vessel

containing the liquid is then placed on a table which can be raised very gradually and steadily by a screw. After the scale point touches the liquid the latter is further raised about $\frac{1}{4}$ inch, so that the capillary tubes may be wetted inside above their proper level. The liquid is then lowered and the point of the scale wiped. Finally the liquid is raised very slowly and with extreme caution till the point touches the liquid. The capillary readings may be at once taken either by the naked eye or with a pocket lens, or through a horizontal telescope moving on a vertical stand. With narrow tubes the latter plan has no sensible advantage.

§ 27. That kind of capillarity which may be called negative requires in general for its measurement a somewhat different form of apparatus. Mercury and glass may be taken to represent this relationship. The bore of the capillary tube having been measured as before, it is connected by a caoutchouc tube (fig. 12) with a wide transparent reservoir of mercury, such as a wide glass tube drawn out at the bottom and turned up. The two are partly filled with mercury, and the levels are read off by a distant telescope or by a cathetometer. It is best to take the larger tube so wide that its capillarity can be neglected. The depression of the level in the narrow tube is found to be inversely proportional to its diameter or radius.

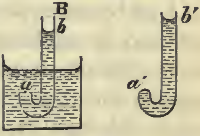
FIG. 12.



All phenomena of capillarity seem to show that the raising or lowering of the liquid level is brought about by the shape of the free liquid surface. The shape itself is determined by the relation between the cohesion of the liquid and the adhesion between the liquid and solid.

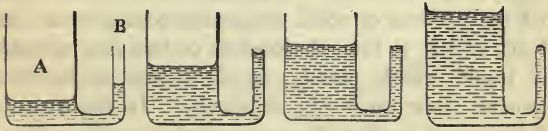
§ 28. If we immerse fig. 13, a capillary U-shaped tube, in water so that its shorter limb *a* is covered, the liquid stands at *b* in the longer limb B. On withdrawing the reservoir, the liquid surface at *a* becomes convex, and there is a certain difference in height between a' and b'. On touching the convex surface at a' with blotting paper, some of the water is removed and the surface becomes flatter. When it is quite flat there is the same difference if level between a' and b' as there was between *b* and the liquid in the reservoir.

FIG. 13.



Again (fig. 14), let a wide

FIG. 14.



tube A be connected with a capillary tube B. Pour water into the two, and you get a definite capillary elevation, which difference is maintained until the liquid reaches the top of the narrow tube; the surface of the liquid in this tube then begins to flatten, and when it is quite flat the level in both tubes is the

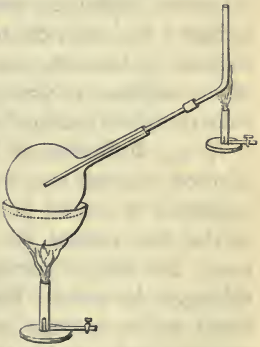
same ; on adding more water to the wider tube, the level in it may be raised considerably above that in the narrow tube, the surface in which becomes then convex.

§ 29. The connection between the curvature and the cohesion and adhesion is generally attributed to an alteration in the density of the liquid at and near the solid. Without discussing this question, the relative capillarities of different liquids in regard to the same solid can be at once measured by replacing the water of § 26 by other liquids. With regard to the variation effected in capillary height by variation in the solid, it is difficult, if not impossible, to obtain tubes of exactly the same diameter and of different material. And although, assuming that the law of capillarity holds good with all solids and all liquids, we might make use of tubes of different diameters, it is far easier to apply drop-size, §§ 12, 13, for this purpose, for, like height, drop-size is affected positively by the increased cohesion of the liquid and negatively by its density. In most cases it has to be borne in mind that the surfaces of solid bodies are coated with films of air, and it is the relationship of this film towards the liquid which mainly, at all events at the first moment, determines the capillarity. In the vacuum of the most perfect barometers the surface of the mercury is perfectly level, and allowance for capillarity in the tube rather introduces than eliminates error.

COHESION OF SOLIDS AFFECTED BY THEIR ADHESION TO LIQUIDS. SOLUTION.

§ 30. The degree of solubility of solids in liquids is so much affected by temperature that it will have to be mainly considered in connection with HEAT. Also the rate of solution in so far as it is affected by convection currents of course depends upon temperature. With regard to the comparative solubility of salts at the same temperature, a few hints may be here given. As solutions of salt in water are always heavier than water, the salt in order to saturate the water must be frequently stirred with it, or far better, it is hung in a muslin bag at the surface of the water. If, as is almost invariably the case, it is more soluble in hot than in cold water, it is heated with water till the water is so far saturated that a portion of the salt separates out on cooling to the required temperature. If the first plan is adopted, the solution should be allowed to evaporate till salt begins to separate.

FIG. 15.



§ 31. To determine the quantity of salt in a solution, a long-necked flask of hard glass is dried and weighed, and a few grams of the solution being introduced by a pipette without soiling the neck, the flask and solution are weighed

together. The flask is tilted on one side, and the water is evaporated off without boiling. Such evaporation may be advantageously assisted by a current of air, which may be caused to flow over the surface of the liquid by inserting a glass tube, *t*, open at both ends, and heating the projecting part, which thereupon acts as a chimney. Or the neck of the flask may be connected with an exhauster such as a water air-pump.

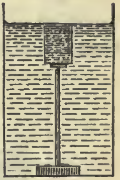
§ 32. How far a salt may be heated to get it anhydrous without decomposing it depends upon its chemical nature, and for this and for the determination of the quantity of the salt or its constituents by precipitation, the reader is referred to chemical treatises. It may be useful, however, to know for physical experiments that the following amongst the more common salts become perfectly anhydrous at 110° C. without undergoing the slightest decomposition: the chlorides, bromides, and iodides of potassium and sodium; the chloride of ammonium; the nitrates of sodium, potassium, ammonium, lead, barium, and silver; sulphate of potassium, chromate of potassium, chlorate of potassium, bichromate of potassium, etc.

§ 33. **Diffusion of Liquids into Liquids.**—The solution of a salt in a liquid only presents the simple condition of contact between pure salt and pure water at the first instant of contact. Immediately afterwards the salt is surrounded by a salt solution, and this again by water. Further mixture is then brought about by the passage of salt from the salt solution into the water, for it is this passage which enables fresh portions of the salt to leave the mass. The

mixture of a salt with water by diffusion appears to be due to the motion of the salt itself, and not to the solution of it.

§ 34. The diffusion of salts through water may be measured by the arrangement represented in fig. 16. A cylindrical vessel about 1 in. diam. and 4 in. high is placed on a glass support in a beaker; the cylinder is filled up to the brim with a solution of a salt of known strength, say 6 per cent. Water is then poured into the beaker so as to be about $\frac{1}{8}$ in. above the edge of the cylinder. Diffusion at once begins, the salt solution pours over the edge of the cylinder, and is replaced by nearly pure water at the mouth of the cylinder. After the lapse of a given time, the contents of the beaker are run off by a siphon into a basin, into which the outside of the cylinder, the stand and the beaker are all washed. The amount of dry salt is determined by evaporation and weighing the residue, as in § 31. A 6 per cent. solution of some other salt being experimented on under like conditions, the ratio between the two residues is the relative diffusion. It is obvious that this kind of experiment is so far defective as after a time the diffusion of the salt takes place into a salt solution instead of into water. And this occurs soonest with those solutions whose diffusion is the greatest.

FIG. 16.

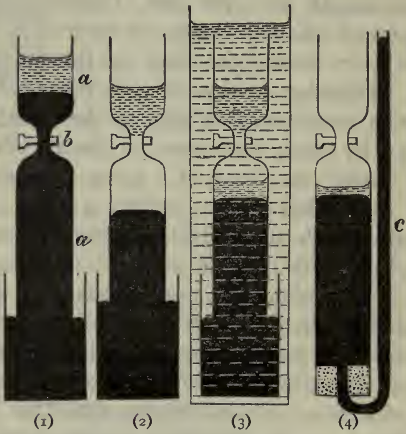


§ 35. Chloride of potassium and sulphate of potassium are convenient salts to compare, for they differ considerably in diffusibility (in the ratio of 1 to 0·6987) and are both readily estimated by evaporation. On

comparing in this way solutions of various strengths of the same salts, the generalisation is established that the rate at which a soluble salt diffuses from a stronger to a weaker solution is approximately proportional to the difference of strength between two contiguous strata.

§ 36. **Diffusion of Gases into Liquids. Absorption.**—A simple, and for most purposes sufficiently

FIG. 17.



exact absorptiometer, is constructed and used as follows. A tube (fig. 17) *a*, about the diameter of a burette, is drawn to a neck in the middle, and a very well-fitting glass stop-cock, *b*, is then inserted. Both above and below the cock a millimeter scale is etched on the glass, and the tube is calibrated. By a cork fitting the top, and a piece of tubing through the cork, mercury is drawn up out of a trough past

the stop-cock, which is then turned off. The gas to be examined is introduced below, and the liquid (say thoroughly boiled water) is put into the upper tube. The cock is now turned till the whole of the mercury, but none of the water, has passed into the lower tube. It is then turned off, and the level of the liquid read off in the upper tube, and that of the mercury in the lower one (2). Next the cock is turned, and some of the water is run in. The quantity is known from the sinking of the water in the upper tube, and the applied calibration of that part. After standing a few minutes, the thumb well smeared with burnt caoutchouc is pressed upon the opening of the lower tube, and the whole is taken out of the mercury trough and well shaken. This is done several times at intervals, the tube always being opened under the mercury. Finally, the whole, mercury trough and all, is placed in a capacious beaker, and surrounded with water of the temperature of the air, and the height of the mercury read off (3). The pressure to which the gas is subjected, and under which absorption has taken place, is measured by the barometric pressure at the time diminished by the difference between the heights of the mercury inside and outside the tube. The inside column is assisted by the column of water above the mercury. If we wish to experiment with pressures above the atmospheric, a bent tube, *c* (4), the shorter limb of which passes through a caoutchouc stopper, is fixed into the lower end of the absorption tube, and any required quantity of mercury is forced into *c* till a given pressure is reached.

§ 37. It seems that the quantity (mass, weight)

of a given gas which a given liquid absorbs, is almost exactly directly proportional to the pressure. Since the density varies directly as the pressure, it follows that a liquid absorbs the same constant volume of a given gas, whatever the pressure may be. The 'coefficient of absorption' is the volume in cubic centimeters (reduced to 76 cm. pressure and 0° C.) of the gas which 1 cubic centimeter of the liquid absorbs at atmospheric pressure (76 cm.). This coefficient varies greatly with the temperature, the quantity absorbed being always less at higher than at lower temperatures. The coefficient of absorption should therefore be referred to some fixed temperature, say 0° C.

§ 38. **Condensation of Gases by Solids. Occlusion.** —Porosity seems to be always comparative, so that condensation of gases into the pores of solid bodies is continuous with the penetration of a gas into the densest metals. To measure exactly the volume of a gas which a solid will absorb, the gas may generally be collected over mercury in a graduated and calibrated tube. The solid which has to effect the absorption must be first deprived of any gas which may be in it. For a mere qualitative experiment, that is, to show the fact of absorption, the solid should be heated as hot as it will bear in an air-gas flame, and be plunged under the surface of mercury. This process answers well with charcoal. A barometer tube is filled with dry gaseous ammonia, so that the mercury is at the same height inside as outside the tube, and the gas is therefore at atmospheric pressure. Now pass up a pellet of hard charcoal, which has been heated and quenched as

described, into the gas : absorption at once begins, and the charcoal absorbs nearly a hundred times its own volume. To measure the absorption exactly, a pellet of hard charcoal, such as cocoanut charcoal, is placed in a tube, one end of which is closed ; the other end is fastened to the mercury air-pump, and the glass is heated as hot as it can be without softening while the pump is in action. The caoutchouc joint connecting with the pump is drawn out and pinched off, so as to preserve the vacuum, and the glass tube, pellet of charcoal, and caoutchouc, are weighed together. Then the caoutchouc is pulled off, the pellet rolled out on to the mercury, immediately plunged beneath its surface, and introduced into the gas. It is better even to heat it again in forceps as high as possible without burning it. The tube and caoutchouc are again weighed by themselves. After absorption appears complete, the eudiometer should be removed to a deep mercury well and lowered into it, till there is the same level inside as out. The temperature is measured by enclosing the whole in a glass cylinder full of water of observable temperature. Diminished by increased temperature, the gas-absorbing power of a solid appears to depend both upon the extent of the porous surface, and on the density of the solid. It also appears that the more easily a vapour is condensible, the greater is its faculty for being absorbed. While some metals act, like silver, which absorbs oxygen while melted and gives it up as it cools, most metals condense gases on their surfaces

FIG. 18.

and absorb them into themselves to the greatest degree when they are cold.

§ 39. If chloride of ammonium be added to chloride of platinum, an almost insoluble double chloride is formed, which, after slight washing, may be strongly heated. Everything excepting metallic platinum is driven off, and this metal then presents the appearance of a spongy grey mass. Held on a platinum wire, a pellet of this will ignite a jet of hydrogen. Brought into oxygen over mercury, it condenses and absorbs that gas.

The gases which have been absorbed by solids can be generally detected and prepared for examination by heating the solid in a hard glass tube in connection with the mercury air-pump. The gases expelled are carried down the moving column of mercury, and are delivered below.

§ 40. It is probable that occlusion is similar in kind to absorption, but as it takes place in compact solids, a different name has been given to it. Metallic iron, when heated and cooled in a current of hydrogen, absorbs and retains about 2·5 times its volume of hydrogen. If iron be deposited electrolytically in a continuous film, which is done by electrolysing a solution of the ammonio-sulphate of iron, a still larger proportion of hydrogen is occluded. When hydrogen is evolved electrolytically at the surface of metallic palladium, the metal absorbs nearly 1,000 times its own volume of hydrogen without losing its lustre. The volume of the palladium is increased during the absorption, and this causes it to curl and twist in a remarkable manner.

§ 41. So great is the attraction between some solids and the vapours of some volatile liquids, that it affords the means of producing extremely perfect vacua. A piece of cocoanut charcoal is placed in a hard glass tube, which is then drawn out at both ends, and contracted to narrow necks. To one end is sealed by fusion a small retort containing liquid bromine. This is heated till it boils, while the carbon is heated as hot as the glass will bear. The further end is then fused off, and the retort is also fused off. As the tube cools the bromine vapour disappears, being absorbed by the carbon, and this absorption is so complete, that if two platinum wires have been previously fused into the tube at a very small interval apart, it is found, as long as the charcoal is cold, that the interval between them is so perfect a non-conductor for electricity that no discharge takes place between them when they are connected with the terminals of an induction coil of such strength that, in air of the ordinary tension, a spark of several inches in length is produced. This implies the existence of as perfect a vacuum as can be got by the most perfect arrangement of the mercury air-pump.

§ 42. **Breath Pictures.**—The film of air which covers most surfaces has a different power of condensing vapours from that possessed by the bare surface of the solid. Hence, if we rub a clean sheet of glass with a point of hard wood or brass, the air-film is rubbed off at the lines of contact, and on breathing upon the glass the invisible lines become visible, for the vapour in the breath is not condensed

upon them. Exposed to the vapour of mercury, the invisible writing on a glass plate may be made permanent. Such breath pictures are best examined by means of daguerreotype plates, that is, plates of copper covered with silver. These are so sensitive that they will furnish a print of a medal or other body which is not even in contact with them. Such a plate will condense the water of the breath as a brownish dew where there is a film of air or gas, but as a bluish dew where there is none. To cover the plate with gas-film it is covered with charcoal which has been saturated with that gas, while to get it quite free it is covered with charcoal which has been freshly ignited, and kept covered while cooling. If, now, the plate has been saturated with a gas, say carbonic acid, by the first plan, and a medallion is placed on it which has been deprived of all gas by the second, the medallion surface will lay hold of a portion of the carbonic acid of the plate, and abstract more the nearer it is to the plate. On afterwards breathing on the plate, the parts of the plate which were nearest to the medallion will be covered with a bluish dew, the other parts with a brownish dew. This shows that the metallic surfaces can exert actions upon each other at perceptible distances; possibly every metallic surface is in a similar condition to that of a free surface of mercury, which is found to be clothed with an atmosphere of mercury vapour, so closely bound to the liquid, that at ordinary temperatures and atmospheric pressures its presence cannot be detected at ·1 millimeter above the surface, and which, in still air, protects the mercury from further vaporisation.

§ 43. **Diffusion of Gases into Gases.**—The unhampered diffusion of gases into gases has been but little studied. The essential conditions for experiment are of course that the heavier gas should be below, that the two should, at a given time, be brought into contact without disturbance, and that the condition of the mixture at the end of a given time should be ascertainable without disturbance.

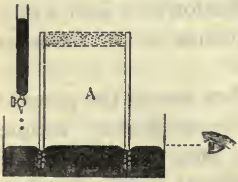
§ 44. That gases mix with one another rapidly and perfectly by diffusion is seen by filling two wide-mouthed bottles over water with any two gases, covering their mouths with glass plates, turning that one over which contains the lighter gas and placing it on the other one so that the two plates are in contact. On sliding the plates out and replacing them after only a few seconds the contents of the two are found to be identical: namely half and half, if the vessels are of equal capacity. This being so it follows that half the number of atoms of the lower gas have passed up and half those of the upper have passed down through the original common surface at the vessels' mouths. But it by no means follows from this that the diffusive energy of A into B is equal to the diffusive energy of B into A, because under the condition, the sum of the volumes being constant, the diffusion of A into B may be both a cause and a consequence of the diffusion of B into A.

And this being true also when one of the gases is unlimited in volume, makes the apparently simple phenomenon really a complex one, even when the vessel has the simplest (cylindrical) form. A glass cylinder A (fig. 19), about 6 in. long and 1 in. internal

diameter, is closed at one end, the other end has ground into it a glass stopper carrying a tube an inch long and $\frac{1}{8}$ in. internal diameter ground flat on the top. The stopper being greased, the cylinder and tube are filled with mercury and then by displacement nearly filled with the gas. A glass plate is pressed on to the end of the narrow tube and the whole is carried to a room of uniform temperature where it is supported in a clamp. If the gas be lighter than air (nitrogen, hydrogen, coal gas) the narrow tube is directed downwards—otherwise upwards. The glass plate is removed for a given interval of time. It is then replaced and the mercury shaken up in the two tubes. A sample of the gas is then taken out for analysis. The actual quantity of the gas which has diffused out is proportional with the same gas to the sectional area of the exposed surface. The generalisation which has been established experimentally is that with different gases under the same conditions the quantities vary inversely as the square roots of the specific gravities. This generalisation is more closely reached if instead of one large surface of contact a number of small ones are used, such as exist in a thin plate of plaster of Paris, or artificial graphite. And the adoption of such a device enables us to measure the ratio of exchange between two gases in the following manner. A glass tube A (fig. 20) is fitted with a solid

FIG. 19.

FIG. 20.



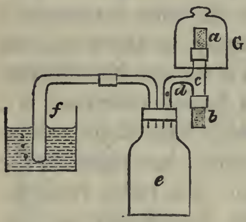
cylindrical plug which is pushed in to about $\frac{1}{8}$ in. from the end. Fine plaster of Paris paste is poured upon the top of the plug. After a time the latter is withdrawn and the plaster is allowed to dry for a day or two. A piece of sheet caoutchouc is stretched over it and tied tightly round the top. The tube is filled with a gas over mercury. The caoutchouc is taken off, and diffusion through the plaster at once begins. In the case of gases lighter than air the mercury is seen to rise in the tube. With gases heavier than air it falls. Since difference of pressure affects the rate, it is necessary to keep the pressure constant. This is done either by dropping mercury into the trough from a pipette or letting it run out through a siphon. By constant watchfulness the mercury is kept at the same level inside as out. After a time the caoutchouc covering is tied on again and a sample of the gas analysed. Or another way of performing the experiment is to maintain the level as long as any tendency to change manifests itself. The volume of the air (nearly pure atmospheric) which is now in the tube is compared with the volume of gas originally in the tube, and the second divided by the first is the specific diffusion of the gas in regard to air. As however air itself is a mixture, the constituents of which have slightly different diffusion rates, the gas which has replaced the escaped gas is not quite pure air: it is rather richer in nitrogen. The absolute error introduced on this account is very small, and the error affecting the comparison between two gases in the tube is only a small fraction of the absolute error. The whole apparatus may be enclosed in a bell-jar of continually renewed

carbonic acid, while the adjustment of the level of the mercury may be effected by tubes passing through the supporting table.

§ 45. The same relation is found to exist (when the porous plate is thin) between the diffusive powers through plates as that which exists with free intercourse, namely that the volume passing varies inversely with the square root of the specific gravity of the gas. So that if the tube A were filled with hydrogen (density$=1$) and surrounded by oxygen (density$=16$), four vols. of hydrogen ($\sqrt{16}$) would pass out for every 1 vol. of oxygen ($\sqrt{1}$) which entered. When all the hydrogen had escaped therefore the distance between the mercury and the plaster would be one-fourth of what it was when the tube was full of hydrogen, supposing the pressure to have remained the same throughout on both sides of the plaster.

§ 46. To merely exhibit this differential diffusion, two round porous earthenware battery cells *a*, *b*, are fastened by caoutchouc connectors to a glass tube *c* from which a horizontal tube *d* bent at right angles enters a safety flask *e*, through whose cork passes a second tube *f* which dips into coloured water; on placing a bell-jar G containing hydrogen or coal gas over *a*, air is driven out of *f*; on filling the jar G with carbonic acid and surrounding *b* with it, the liquid in *f* rises.

FIG. 21.

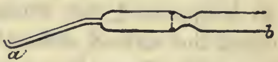


§ 47. **Effusion.**—A distinction is generally made between the passage of one gas into another by

diffusion through porous solid, which is always a reciprocal motion, and the passage of a gas through one or more holes in a solid into a more or less complete vacuum. The first kind of motion is in the strictest sense molecular, for on mixing gases the molecules of each are separate. The gas in the second case moves in currents.

§ 48. A hole not larger than a pin-hole is bored through a thin circular plate of brass or platinum. The sides of the hole are hammered and the hole rebored until under a hand lens the edges appear flat and smooth (fig. 22). The edge of the plate is then coated with a rim of shellac and dropped into a glass tube having a waist narrower than the metal disc. The whole is held nearly vertically and warmed to melt the shellac, so that a perfectly air-tight connection is made. One end of the tube is drawn out and bent down so as to serve as a delivery tube; the other is connected with an apparatus to be described in § 59, whereby a constant pressure is maintained. The quantity of gas which passes through the perforation in a given time is measured. The motion is here caused of course by the difference of pressure on the two sides of the hole, the pressure at one side being that of the atmosphere. To measure what is generally understood by effusion the end *a* is left open and the end *b* is connected with a mercury air-pump. The gas which is drawn out of *b* is collected and measured. For gases other than air the gas is placed in a loose bag connected with *a*. A convenient form

FIG. 22.

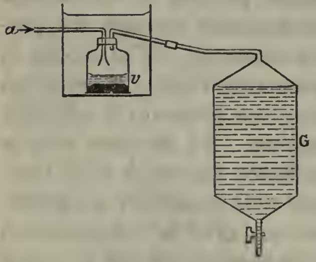


of orifice for effusion experiments is shown in fig. 23, where the glass tube *a* is heated at its end and allowed nearly to close. It is cemented into another tube with shellac. For openings which are so large that the mercury air-pump cannot be depended on for maintaining a constant vacuum, an ordinary air-pump with a barometer gauge will answer, but there should be interposed between the pump and the tube a reservoir vacuum. The gas may in this case be contained in a gasometer, which must be maintained so as to give a constant pressure.

FIG. 23.

§ 49. **Diffusion of Liquids into Gases.**—In §§ 44–46 it appeared that when one gas diffused into another, the second diffused into the first. It appears also that whenever a gas is soluble in a liquid the liquid is aerifiable into the gas. The cohesion of liquids, whereby their aerification is restrained, depends so much upon their temperature that we shall have to reconsider the question under HEAT. The apparatus used for measuring the rate of evaporation which liquids exhibit under like conditions is as follows. The gas which is to effect the evaporation enters at *a* from a limp bag; and it is drawn over the liquid by means of the flow of water from the gas-holder, G. The liquid to be

FIG. 24.



evaporated is in the cylindrical vessel. At the bottom of *v* is a considerable quantity of mercury, above which is the liquid. The tube for the entrance of the gas is widened into a funnel-shape, and the throat of the funnel is partly choked with cotton-wool. The cork is made tight with a large quantity of shellac, having a smooth surface. The gas exit and entrance tubes pass water-tight through the sides of a vessel containing water. The water maintains the temperature constant. The mercury prevents *v* from floating. The funnel-shaped opening containing cotton-wool prevents the liquid from presenting an irregular surface through disturbance. Dry air is first passed through the apparatus, so as to dry up any of the liquid which is sticking to the glass. The whole is wiped dry and weighed. Having been put together and the joints made tight, a known quantity of water is allowed to flow out of G, and that this flow should be uniform it should be delivered into litre flasks of which one may fill every five minutes. After a known quantity of air or gas has been drawn over, the vessel *v* is removed, dried, and re-weighed.

§ 50. Experiments show that the more a gas is soluble in a liquid the more is the liquid volatile in the gas. Thus water is more volatile in oxygen than in hydrogen, or nitrogen, or olefiant gas, while alcohol is more volatile in the latter gas than in any of the others. Water at its maximum density, that is 4° C., is less volatile than at higher or lower temperatures. Such differences only refer to the rate and not to the final amount of the liquid volatilised. For if a liquid be introduced into a gas in a barometer tube standing

over mercury, the depression of the mercury will be the same whatever be the nature of the gas, showing that the same quantity or volume of vapour has been formed.

§ 51. **Vapour Tension.**—Looking upon a liquid evaporating in the air, we find the evaporation proceed against and overcome the air pressure. In order to find with what pressure the vapour separates itself from the parent liquid, that is the vapour tension of the liquid, the atmospheric pressure must be removed. It is clear that a body in the barometric vacuum is not subject to any pressure at all, and accordingly if a liquid be introduced into the vacuum the depression it causes in the mercury measures its spring or vapour tension.

§ 52. For most purposes the simple 'eudiometer' tube serves for such measurement. A millimeter scale is either etched on the tube or supported closely behind it, the readings being taken through a vertically sliding telescope. In comparing different liquids at the same temperature, if that temperature be the atmospheric, the barometer tube after being filled with mercury is inverted into a trough having plate-glass sides. The height is measured inside and outside the tube, and the difference is the barometric height. A sufficient quantity of the liquid is introduced by a small bent pipette for there to be a little of the liquid remaining as such above the mercury. The difference of the new heights of the mercury inside and outside now represents the atmospheric pressure minus the vapour tension. So that the vapour tension is the difference between the first pair of dif-

ferences and the second. This would be exact if the liquid were only just but completely evaporated. As, however, to ensure saturation of the vacuum it is best to allow a little liquid to remain, the weight of this has to be added to the weight of the internal column of mercury. The height of the bottom of the liquid column may be taken as that of the top of the mercury column. The top of the liquid column is taken as the lowest point of its upper surface. To translate the liquid column pressure into mercury pressure, that is, to find what length of mercury would have the same downward pull as the observed length of liquid, the length of liquid must be divided by the ratio between the density of mercury and the density of the liquid, or what comes to the same thing, the ratio between the specific gravity of the mercury and that of the liquid.

FIG. 25.

§ 53. Let, for example, a barometer tube be filled with mercury and inverted.

	mm.
Let the reading of the mercury inside the tube be	780·2
Let the reading of the mercury outside the tube be	30·5
Then the barometric height (atmospheric pressure)	=749·7

Let a liquid be now introduced which has the specific gravity of 0·872, and let the upper surface of the liquid stand at 540·4 mm., the lower surface of the liquid stand at 535·0 mm., the inner surface of the mercury

stand at 535·0 mm., the outer surface of the mercury stand at 40·6 mm. Then inside the tube there are 535 mm. of mercury and 5·4 mm. of liquid. The 5·4 mm. of liquid are equivalent to $5·4 \times \frac{·872}{13·5}$ mm., or 0·3 mm. of mercury. So that inside there are 535·3 mm., and outside 40·6; so that the mercurial pressure, that is, the difference between the atmospheric pressure and the vapour tension, is 494·7 mm. The atmospheric pressure being 749·7, the vapour tension is 255·0 mm.

How vapour tension varies with temperature will be described in the treatise on HEAT. It may be here mentioned that the additional elements to be taken into account are (1) the variation in density of the mercury according to temperature, and (2) the elongation of the scale if it be etched on the glass.

§ 54. The vapour tensions of solids are measured in a similar manner. In order to avoid the irregularity of the mercury surface when a solid rests upon it, the barometer tube may be made double, and one limb being graduated, the solid is introduced into the other. This form of barometer is indeed or liquids also advantageous, because the liquid being introduced into one limb, the height of the mercury in the other has not to be corrected for the liquid column. By this means, or by a series of barometer tubes arranged side by side, it is easy to show that the vapour tensions of saline solutions are less than those of water, and are less according as the solutions are

FIG. 26.

stronger. Also that the solid water in crystalline salts containing water of crystallisation has various vapour tensions, while the water in solutions however strong of gums, glues, or other colloidal substances, exerts the same vapour tension as pure water, and indeed that the water in gelatinised colloid solids (jellies) has precisely the same vapour-tension as water itself.

§ 55. That colloid bodies have little or no hold on water and other crystalloid bodies (the terms will be more fully explained in §§ 57, 58) is shown very simply on placing some strong solution of gum arabic in a basin under the receiver of a good air-pump. On rapid and nearly complete exhaustion being effected, the gum boils violently. If a 50 per cent. solution of glue be placed in a test tube, and surrounded with water in a larger tube, the glue solution boils before the water if the latter be heated very gradually. The glue solution boils in fact at 97·5° C.

§ 56. **Diffusion of Liquids into Solids. Osmose.**—It seems that no liquid can penetrate through a crystalline solid without dissolving it. By enormous pressure water can be forced through masses of iron as in the cylinders of hydraulic presses, but it seems from analogy probable that the water passes between the crystals of iron and not through them. Bodies which as solids show no traces of crystalline form are called amorphous, their fracture is conchoidal. Such bodies are glass, resin, glue, gum, some varieties of quartz, caoutchouc. Such of these as are soluble in liquids, as gum and glue in water, or resin in alcohol, may or may not form jellies with the liquid. Thus gum arabic does not, but gelatine on being heated with water does,

on cooling, form a jelly. So does caoutchouc with benzol. A jelly appears to be the result of the partial reaggregation of the particles of the colloid.

Perhaps melted caoutchouc and fused glass may be considered to be colloid liquids. A colloid solid, even when insoluble in a liquid, may and often does allow that liquid to penetrate it, but it does not allow colloids to pass through with anything like the same facility. The passage of crystalline solids in solution and liquids through colloid septa is properly called osmose. 'Vegetable parchment' or 'parchment paper' is convenient for studying osmose (*see* Appendix). A glass tube about 1 in. wide and 2 in. long has a piece of parchment paper tied tightly over one end. The tube is then weighed, partly filled with a salt solution of known strength, and again weighed. It is then immersed to such a depth in distilled water, in a wide basin, that the upward and downward pressures at the parchment surface are as nearly as possible equal. The inner vessel gains in weight, but loses in salt. The quantity of water which has passed inwards minus the quantity of salt which has passed outwards is the difference of the first and second weighings. The absolute quantity of salt which has passed outwards is got directly by evaporating the contents of the outer vessel, or indirectly by evaporating those of the inner vessel, and subtracting from the amount known to have been there to begin with. In such cases it is difficult to say whether there is an exchange between salt and water or between salt solution and water. But the balance of motion is in favour of the water. Thus, if a bladder be used about 4·5

times as much by weight of water passes to the salt solution as of salt to the water, if the salt be chloride of sodium. The osmic equivalents of other salts are determined in the same way. But the osmic equivalents depend also upon the nature of the membranes. Bladder gives different values from vegetable parchment.

§ 57. **Dialysis.**—The difference referred to above seems to depend upon the power which the membrane has of absorbing one or other liquid. A piece of bladder softens and swells in water, but hardens and shrivels in alcohol. Placed between water and alcohol, the former penetrates it and diffuses from the other side into the alcohol, while little alcohol can pass the other way. Take now caoutchouc instead of bladder; this softens and swells in alcohol, but is almost impermeable to water. If accordingly a caoutchouc membrane separates alcohol from water, the alcohol will pass through and little or no water will return. It is thus that wine strengthens in skins and bladders, but weakens in caoutchouc bags. Water, however, passes in some quantity through caoutchouc. A toy air-ball, for instance, if completely filled with water and perfectly closed will go on losing water with great regularity for weeks. And if dry air be passed along two tubes joined together by a piece of caoutchouc tubing which is immersed in boiling water, the air will be found to be no longer dry. The facility with which crystalloid bodies in solution pass through many colloid membranes, and the hindrance almost amounting to obstruction which the same membranes present to colloids, render the separation of colloids from crys-

talloids easy in cases where it would be difficult to effect the separation by other means. The dialyser consists of a sheet of parchment paper stretched between two concentric hoops of gutta-percha. This tabor which may be filled with a mixture of gum and salt in solution is floated on pure water. After some days, the outer water being removed, scarcely a trace of salt is found in the tabor, while scarcely a trace of gum has passed out of it. It is thus that the metallic and alkaloid poisons may be separated from the colloidal mucilage of the contents of the stomach, while of course the most effective filtration accompanies the dialysis.

It appears that the oxides of iron, tin, aluminum, and silicon, are or may be colloidal, and may be then either soluble or insoluble in water.

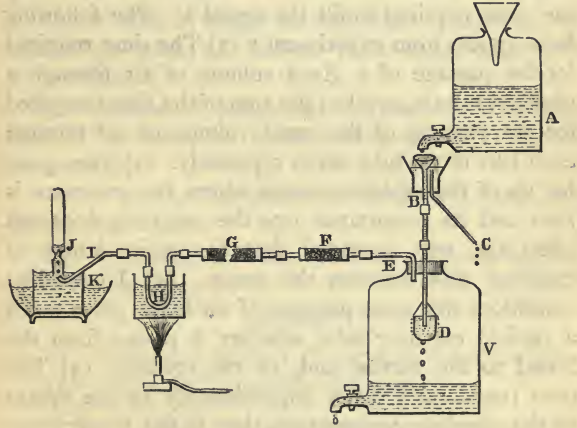
§ 58. To obtain soluble oxide of iron, hydrochloric acid is digested with freshly-precipitated hydrated sesquioxide of iron until no more is dissolved. Placed in the dialyser, hydrochloric acid alone passes through, leaving the oxide of iron in solution in water; after some days the separation is complete. The solution is very apt to gelatinise, and will not again dissolve by adding more water or heating. Soluble alumina may be got in a similar way. Soluble silica is prepared by adding basic silicate of soda (soluble glass) to an excess of hydrochloric acid and dialysing as above.

§ 59. **Transpiration of Gases through Capillary Tubes.**—The amount (volume) of gas which passes in a given time through a tube depends upon the width and length of the tube, upon the difference of pres-

sure between the two ends of the tube, upon the temperature of the gas and upon its density. For measurement, each of these factors must in turn vary, all the rest being constant. The apparatus of most general use is shown in fig. 27.

Water dropping from A is made to continually overflow the funnel tube B : the overflow being carried away

FIG. 27.



by C. B passes air-tight through a cork in the mouth of a vessel V, and dips beneath the surface of the water in the little tube D.

The gas in V escapes by the tube E, and after being dried in the two tubes F and G, passes into the tube H, the lower part of which is capillary, and which is surrounded by a vessel to hold ice, or hot

water, or paraffin, &c. Thence the gas escapes through I, and is collected in the tube J, which is constricted and marked at J, and stands in an overflowing vessel K. The effective pressure on the gas, that is the difference between the pressures at the two ends, is independent of the barometric pressure, and is measured by the length of the column from the surface of the water in B to the surface in D. And this length remains the same. The rate is measured by the time required to fill the vessel J. The following facts appear from experiment: (1) The time required for the passage of a given volume of air through a capillary tube is equal to the sum of the times required for the passage of the same volume of air through each part of the tube taken separately. (2) The opening up of the tube into spaces where the resistance is zero and its re-entrance into the capillary does not affect the rate, provided that the entire length of capillary tube remains the same. (3) Under like conditions the same passage of air takes place down a conical capillary tube, whether it passes from the broad to the narrow end, or the reverse. (4) The time (resistance) varies approximately as the square of the absolute temperature, that is the temperature measured from $-273°$ C. (5) The time varies nearly exactly inversely as the pressure, but rather more rapidly than that reciprocal.

DENSITY, COMPARATIVE WEIGHTS OF EQUAL VOLUMES, ABSOLUTE WEIGHTS OF UNIT VOLUME, SPECIFIC GRAVITY.

§ 60. The exact methods adopted for finding the specific gravities of bodies vary according to the nature of the bodies. We will consider separately the following cases :

Solids.

(1) A solid in lumps not less than a hazel nut, insoluble in water, (*a*) heavier than water, (*b*) lighter than water.

(2) A solid in lumps not less than a hazel nut, soluble in water, (*a*) heavier than water, (*b*) lighter than water.

(3) A powder insoluble in water, (*a*) heavier, (*b*) lighter than water.

(4) A powder soluble in water, (*a*) heavier, (*b*) lighter than water.

Liquids.

(5) A liquid to be had in considerable quantities.

(6) Very small quantities of liquids.

§ 61. A balance suitable for taking specific gravities should, when loaded with 50 grams on each pan, show the effect of 0·0002 gram. Most balances are provided with a short-slung brass pan having a hook at its bottom. This brass pan is sometimes lighter and sometimes heavier than the pan on the other side. If lighter it is best to add a chip of glass or a watch-glass to make it heavier. It is not advisable to attempt to make or use a counterpoise. Weights

are added to the weight pan till there is equilibrium, and the weight so added has to be deducted from all subsequent weighings. This is not necessary when as in (3), (4), (5), (7) and (8) an apparatus is weighed along with the substance: for then the error of the balance counts as weight of apparatus.

The most usual way of performing the determination of (1) depends upon the fact that a body totally immersed in water is buoyed up by a force equal to the weight of water it displaces, that is by a force equal to the weight of water having a volume equal to the volume of the body. In other words, the weight which a body loses in water is the weight of water whose volume is equal to its own. And the specific gravity of a substance, being the ratio between the weight of any volume of the substance and the weight of an equal volume of water, is got by dividing the weight of the body by the weight which it loses in water. We may here neglect the buoying effect of the air upon the body and the weights.

§ 62. As an example of (1*a*) we may take quartz. A watch-glass placed on the substance pan is counterpoised by 4·3256 grams. A lump of quartz is placed on the watch-glass and the two require 5·7237. Accordingly, weight of quartz (in air) = 1·3981.

The quartz is tied to a fibre of cocoon silk having a loop at the other end, so that when hanging by the loop from the hook of the substance pan the quartz is about two inches from the bottom of the balance (or pan support). Being so hung it is again weighed (the watch-glass remains). The new weight is 5·7244. The silk fibre weighs therefore 0·0007.

Breathe on the surface of the quartz and hang it in a vessel of distilled water of such a width that the quartz may swing freely, and of such a height that about half the silk is immersed. Any air bubbles which adhere to the quartz are teased off with the feather of a pen. Let the weight in the water be 5·1270. Since the silk fibre has very nearly the same density as water, the part immersed does not affect the weight. The part outside may be taken as 0·0003, so that 5·1267 is the weight of the watch-glass and immersed quartz. And therefore 5·7237 − 5·1267 or 0·5970 is the weight lost by the quartz, that is the weight of an equal volume of water, and therefore

$$\frac{1{\cdot}3981}{{\cdot}5970} \text{ or } 2{\cdot}342$$

is the specific gravity of this specimen of quartz.

§ 63 (1*b*). To find the specific gravity of a solid insoluble in water and lighter than water, the device is employed of fastening to it a body of sufficient weight to sink it. Example:

§ 64. Let it be required to find the specific gravity of paraffin. Let the weight of the paraffin in air be 4·2730. A piece of lead, weighing in water say 7·5964, is stuck to the paraffin. The two together weigh in water 6·4236. Accordingly the weight lost by the paraffin is equal to the weight of the paraffin in air + weight of lead in water diminished by the weight of both together in water, or

$$= 4{\cdot}2730 + 7{\cdot}5964 - 6{\cdot}4236 = 5{\cdot}4458.$$

Therefore the specific gravity of the paraffin is

$$\frac{4{\cdot}2730}{5{\cdot}4458} \text{ or } 0{\cdot}7846.$$

§ 65. **Solids soluble in Water.**—(*2a*). We wish to find the specific gravity of a salt which can be obtained in pretty large crystals like rock-salt, washing soda or alum. A piece of the salt is found to weigh 5·2103 grams in air. Next it is weighed in some liquid of known specific gravity in which it is insoluble, say oil of turpentine of specific gravity 0·8742. Let its weight in turpentine be 3·7020. The loss in weight in turpentine, that is the weight of an equal volume of turpentine, is 1·5083. What is the weight of this same volume of water? Since

$$\text{sp. gr. of turpentine} = \frac{\text{wt. of any vol. of turpentine}}{\text{wt. of equal vol. of water}}$$

$$\frac{\text{wt. of any vol. of turpentine}}{\text{sp. gr. of turpentine}} = \text{wt. of equal vol. of water}$$

or

$$\frac{1{\cdot}5083}{0{\cdot}8742} = \text{wt. of equal vol. of water}$$

$$= 1{\cdot}7254$$

And therefore the specific gravity of sal

$$= \frac{5{\cdot}2103}{1{\cdot}7254} = 3{\cdot}0198.$$

§ 66. (*2b*). A solid lighter than water and soluble in it. Such substances are rare; some kinds of shaving soap are of this nature. The methods of *1b* and *2a* are combined. That is, a known weight of the substance is weighted with a sinker whose weight in a suitable liquid of known specific gravity has been ascertained.

Thus, weight of soap $= 5{\cdot}7321$ grams.
„ sinker in turpentine $= 2{\cdot}4050$ „
Let weight of both in turpentine $= 2{\cdot}4011$
$\therefore$ wt. of turpentine having vol. equal to soap $= 5{\cdot}7360$.

$\therefore$ wt. of water having vol. equal to soap $= \frac{5{\cdot}7360}{0{\cdot}8742} = 6{\cdot}5614$.

$\therefore$ sp. gr. of soap $= \frac{5{\cdot}7321}{6{\cdot}5614} = 0{\cdot}8736$.

§ 67. Before considering 3*a*, 3*b*, 4*a*, 4*b*, it will be convenient to consider liquids. There is great choice in the methods which can be here adopted. The most convenient, and one of the most exact, is that in which the specific gravity bottle is employed.

(5*a*.) A little flask capable of holding about 30 to 50 grams of water has a rather conical stopper perfectly ground into its neck. Through the stopper is a very fine hole; the stopper may be made of a piece of thermometer tubing. The flask is weighed empty. Suppose its weight is $5{\cdot}7230$. As we do not require to know the absolute weight of the flask apart from inequality of the balance, we may here dispense with the preliminary weighing of § 61. The stopper being removed, the flask is filled by a pipette with distilled water until the water is about on a level with the edge. With the exception of the neck it is wrapped lightly in a soft cloth, and being held by the

FIG. 28.

finger and thumb by the neck, and held a little obliquely, the bottom of the stopper is placed in contact with the water, and the stopper is pressed home uniformly, not too quickly and without a grinding motion. The excess of water is so squeezed out, and any drop remaining on the top and about the crack between the neck and the stopper is wiped off, care being taken not to warm the flask and especially not to press in its elastic bottom. It is then reweighed. Suppose it now weighs 36·4723 grams. The water in it weighs 36·4723 – 5·7230 or 30·7493 grams. Let the water be emptied out and the flask thoroughly dried, first by shaking and then by warming with rapid twirling over an air-gas burner and drawing air out of the flask by the mouth with a piece of glass tube. When thoroughly cooled it is to be filled with the liquid as before. Its weight is now found to be say 38·4820. The liquid in it accordingly weighs 38·4820 – 5·7230 or 32·7590, and the specific gravity of the liquid is $\frac{32·7590}{30·7493} = 1·0653$. This method, it is clear, is equally applicable whether the liquid be heavier or lighter than water. The flask may be more rapidly dried if it be rinsed out with alcohol and then with ether.

§ 68. Another method, and one of greater rapidity and almost equal accuracy, is to weigh a conveniently shaped lump of glass suspended from the short scale pan by a silk fibre, as described in § 62, and then to weigh it in succession in air, in water, and in the liquid. Its loss of weight in the liquid divided by its loss of weight in water is the specific gravity of the liquid.

§ 69. Sometimes only very small quantities of the liquid can be obtained. A piece of light tubing (fig. 29) may then be drawn out at both ends as a capillary P. The tube P is then used exactly like the specific gravity flask of § 67, being weighed empty, full of water, and full of the liquid. Liquids which cannot be drawn into the mouth with impunity are drawn into the tube P by means of the enveloping tube Q; the end R is placed in the mouth, P is subsequently removed, and the two capillary ends wiped.

FIG. 29.

§ 70. Occasionally still smaller quantities of liquids are at our disposal. If the liquid be somewhat heavier than water and insoluble in it, the following device may be sometimes used with advantage. A drop of the liquid is placed beneath the surface of a small quantity of water, and a saturated solution of some salt which is without action on the liquid, is added with gentle stirring, till the drop is in indifferent equilibrium. The specific gravity of the salt solution being taken in one of the ways described above, is, of course, identical with that of the liquid drop.

§ 71. (3*a*.) A powder insoluble in and heavier than water. The specific gravity flask is weighed empty, and again full of water; it is then emptied, dried, nearly filled with the powder, and weighed. The powder is covered with distilled water, and put into the air-pump vacuum to remove adhering air; the flask is then filled up with water and again weighed.

Let

Empty flask weigh	$=5{\cdot}7230$	. .	w_1
Flask full of water	$=36{\cdot}4723$	. .	w_2
Flask + powder	$=20{\cdot}2356$	. .	w_3
Flask + powder + water	$=40{\cdot}4038$	. .	w_4

Then—

Water completely filling flask	$=30{\cdot}7493=w_2-w_1$
The powder weighs	$=14{\cdot}5126=w_3-w_1$
Difference between weight of powder and weight of equal vol. of water	$=3{\cdot}9315=w_4-w_2$

∴ Weight of water having same vol. as powder

$$=10{\cdot}5811=w_3-w_1-(w_4-w_2)$$

∴ Specific gravity

$$=\frac{14{\cdot}5126}{10{\cdot}5811}=1{\cdot}3716=\frac{w_3-w_1}{w_3-w_1-(w_4-w_2)}$$

§ 72. (3*b*.) If the powder be lighter than water and insoluble in it, the flask is first weighed empty, then full of water, it is then inverted into a little basin of water, and a quantity of the powder is floated up into the flask, it is re-inverted, dried, and weighed. The water being evaporated off, the flask and powder are weighed together. The data are as in 3*a*.

§ 73. (4*a*.) Let the powder be heavier than water, but soluble in it. Proceed as in 3*a*, but employ some liquid, say turpentine, of known specific gravity (0·8742) in which the powder is insoluble.

Let

Empty flask weigh	. .	$5{\cdot}7230$	. . w_1
Flask full of turpentine	.	$30{\cdot}4723$	. . w_2

Flask + powder . . .	18·9379 .	. w_3
Flask + powder + turpentine	32·4040 .	. w_4

Then $w_3 - w_1 - (w_4 - w_2)$ is the weight of turpentine having vol. equal to that of powder, and therefore

$$\frac{w_3 - w_1 - (w_4 - w_2)}{\text{sp. gr. of turpentine}} \text{ or } \frac{3{\cdot}2149 - 1{\cdot}9317}{0{\cdot}8742} \text{ or } 1{\cdot}467$$

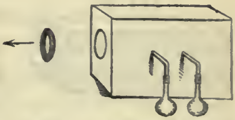
is the weight of water whose vol. is that of the powder, and therefore the specific gravity of the powder is

$$\frac{w_3 - w_1}{1{\cdot}467} \text{ or } \frac{13{\cdot}2149}{1{\cdot}467} \text{ or } 9{\cdot}008.$$

VORTEX MOTION.

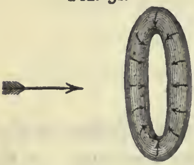
§ 74. As a connecting link between ordinary motion of translation of fluids—air and water currents—on the one hand, and the motion, which gives rise to waves, on the other, stands the beautiful phenomenon of vortex motion, which combines both kinds, and enables a mass of fluid to travel through a mass of fluid without much disturbance to the latter. Smoke rings, gunners' rings, rings following the spontaneous ignition in the air of impure hydride of phosphorus, and occasionally steam rings from locomotives, are familiar examples of these. They can be conveniently shown on a large scale by replacing the back of a box, fig. 30, by canvas or 'duck,' cutting in the front a circular hole,

FIG. 30.



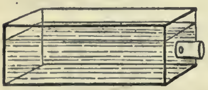
which should have a sharp edge and be provided with a sliding cover. Two flasks, containing respectively ammonia-water and hydrochloric acid-water, are connected by tubes with the inside of the box, and on being heated, fill the inside with clouds of chloride of ammonium. On removing the cover from the hole, and hitting the canvas back, ring after ring of cloud-charged air passes out, and may be made to blow out a candle at ten or fifteen yards. On sending them at a gentle rate, and examining their structure, they are found to have an internal motion, indicated in fig. 31 by the arrows, as though they were rings of elastic material, rolling in tubes touching and exercising friction on their circumferences. A character of these rings is that when they are in rapid movement, general and internal, they show great elasticity one towards the other, in fact, it is impossible to get two to break one another.

FIG. 31.



Similar, but imperfect, liquid vortex rings are seen when ink is dropped gently into water. They are formed in great beauty as follows: a round side-chamber is fastened to the end of a long trough having glass sides. The side-chamber communicates with the trough by a circular opening rather less than the chamber. The other end of the chamber is covered by a stout piece of vulcanised caoutchouc. The trough and chamber are filled with clear water, a little colouring matter is put into the water in the

FIG. 32.



chamber by means of a pipette. The caoutchouc is struck by a round-headed mallet, or thrust in by a lever attached to the trough, resembling a 'lemon squeezer.' If sulphate of indigo is used as a colouring agent, the water soon clears itself if it holds some hypochlorite of lime in solution, and so the trouble of refilling is avoided.

WAVES.

§ 75. **The wave in general.** — Conceive a number, *n*, of particles, exactly alike one another, and arranged in a straight line at equal distances, say one inch apart. Let the particles be called *a*, *b*, *c*, *d*, *e*, &c. Let the particle *a* move in any way, but come back to its original place in the time 10 seconds. Suppose that *b* starts 1 second after *a*, and performs a path just like *a*'s path. Let *c* start 1 second after *b*, let *d* start 1 second after *c*, and so on; each particle completing its course in the same time, 10 seconds, and these courses being identical in size and shape, but differing in position, because the starting points are 1 inch apart. Suppose, now, that when *a* has come back to its original position, that is, after 10 seconds, the particle, *k*, which is 10 inches from *a*, just begins to stir. The particle, *a*, has been moving for 10 seconds, and has completed $\frac{10}{10}$ of its course, the particle *b* has been moving for 9 seconds, and has completed $\frac{9}{10}$ of its course, and so on; the

particle *j* has been moving 1 second, and has completed $\frac{1}{10}$ of its course, the particle *k* is just about to move or just moving, and has completed nothing, or an infinitely small fraction of its course. Let now (at the end of 10 seconds) *a* start afresh as before, and next *b*, and then *c*, and so on, each starting always afresh as soon as it gets home. It is clear that during the next 10 seconds, and ever afterwards, *a* and *k* will be moving alike, and be in similar positions, so will *b* and *l*, *c* and *m*, *d* and *n*, and so on.

The distance from *a* to *k*, or from *b* to *l*, or from *c* to *m*, &c., always in our case 10 inches, is the *wave's length.* Wave-length is the distance between any one particle and the next particle which has completed the same fraction of its course as the first one has completed : this is called being in the same *phase.*

The greatest difference in the positions of one and the same particle is called the wave's *amplitude.*

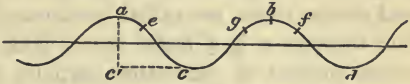
A wave is accordingly a travelling condition of matter in regard to the position of its particles.

It follows from the example that the travelling condition has passed from *a* to *k* in the same time as sufficed to bring *a* back to its original position ; and universally, a wave travels its own length in the same time as that in which any particle completes an entire course.

§ 76. **Waves governed by gravity. Liquid waves.**—These are familiar as water waves. The actual motions of the individual particles, which motions produce the water wave, can be seen if we employ a long trough of water with glass sides, and float a wax

pellet slightly loaded with sand, so that it only just floats in the water, near to the glass side. A paddle, nearly fitting the trough, is placed about 6 in. from one end, and advanced about $\frac{1}{2}$ in. towards the wax, and immediately afterwards back again. This gives rise to a travelling elevation, followed by a travelling depression; these dandle the wax pellet, and it is seen to describe a circle. If the wave's motion is said to be one of advance, the pellet rises advancing, then sinks advancing, then sinks retreating, then rises retreating. The first two parts of the motion are due to the wave's elevation, the latter to its valley. In such a wave each particle describes a nearly circular orbit in a vertical plane which lies in the direction of the wave's motion. The wave-length is from top of crest to next top of crest, *a* to *b*, or from bottom of valley to next bottom of valley, *c* to *d*, or from any particle, *e*, in any phase, to the next particle, *f*, in the same phase. It is clear that particles at the same height are not necessarily in the same phase. The particles *e* and *g*, for instance, are at the same height, but one is going down while the other is going up. The amplitude is the length of the line *a c′*, or the vertical distance between the top of a crest and the bottom of a valley.

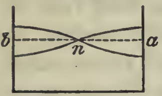
Fig. 33.



§ 77. **Reflexion of water waves. Stationary waves.**—If the wave generated in the trough of § 76 be watched as it strikes the end of the trough, it is seen that the elevation is reflected as an elevation,

and the depression as a depression, also that the height to which the wave rises and the depth to which the valley sinks on reflexion are about double the original wave height. If we use a shorter trough, we can start a fresh wave of such a length and at such a moment that the beginning of the advancing valley of the second wave meets the beginning of the reflected elevation of the first wave in the middle of the trough.

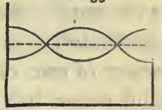
FIG. 34.



The line of particles across the middle of the water surface will then always be urged upwards and downwards by the same pressure, and will not vary in height, and the water will rise at *a* and fall at *b*, and *vice versâ* simultaneously. The particles at *a* and *b* are always in opposite phases, and therefore *a* and *b* are half a wave-length apart, or the wave-length is double the trough's length. The systems of swayings to and fro in this and similar cases, are called 'stationary' waves. The line through *n* is a *nodal* line. With regard to the actual motion of the water particles in such cases, suspended wax pellets show that the actual motion at the reflecting faces is vertical, and that there the motion is greatest. At the node, particles sweep through it in arcs, without altering its height. All the other particles also move in arcs of lesser amplitude as they lie deeper, until at a depth of about a wave-length the movement is inappreciable. If the trough be of a lesser depth, the friction on the bottom retards the wave's motion. The water in a trough can be set in motion in a variety of ways; thus, if the centre be depressed and released, two nodal lines will be formed,

each at nearly $\frac{1}{4}$ the trough's length from the ends. The wave here is half as long as in the former case, or the wave-length is equal to the trough's length. If we count the number of times an elevation appears in the middle in, say, five minutes with the binodal system, and also with the mononodal, we find that with the same trough

FIG. 35.



$$\frac{\text{number with binodal}}{\text{number with mononodal}} = \frac{\sqrt{2}}{1}$$

$$\text{but number of recurrences} = \frac{\text{rate of progression}}{\text{length of path}}$$

calling rate of progression of binodal r_2

" " mononodal r_1

length of path of binodal l_2

" " mononodal l_1 $(=2l_2)$

$$\frac{\frac{r_2}{l_2}}{\frac{r_1}{2l_2}} = \sqrt{2}, \qquad \text{or } \frac{2r_2}{r_1} = \sqrt{2},$$

$$\text{or } \frac{r_1}{r_2} = \sqrt{2}.$$

Or if the length of one wave is twice as great as that of a second, the first will move faster than the second, in the ratio of $\sqrt{2} : 1$.

§ 78. Such waves, in rectangular troughs, are however restrained, and do not move so swiftly as when in open water, or when reflected from the sides of circular troughs. The connection between wave-length and rate of wave progression is practically exhibited

as follows : two cylindrical troughs, which should be at least as deep as they are wide, are nearly filled with water; the bottom of an empty beaker glass is alternately pressed down and raised in the centre of the water of one of them. With a little practice the hand and water help one another. The beaker is withdrawn, and the surface allowed to free itself from ripples. The water is then found to be in the following kind of motion. It sinks in the middle as it rises at the circumference, and *vice versâ*, and the central motion is about twice as much as the circumferential. At almost exactly $\frac{1}{3}$ of the radius from the circumference there is a nodal ring. Such motion will continue for ten or fifteen minutes in troughs of about 2 ft. diameter. The position of the nodal ring, and the amplitude of the motion, can be measured by dipping a sheet of sized paper into the water in a vertical plane along a diameter.

FIG. 36.

If we count how many times the elevation appears in the middle in a given time, we find (1) that whether the undulation is vigorous or nearly expired, the same number of reappearances occur in exactly the same time, and secondly, if the diameter of the trough A is d_a, and that of B is d_b, then if N_a be the number of reappearances in a given time with A, and N_b those with B, we find experimentally

$$\frac{N_a}{N_b} = \frac{\sqrt{d_b}}{\sqrt{d_a}}$$

Now, as before, the number of reappearances of the crest in the middle varies directly with the rate of

progression of the wave and inversely with its length of path. The path is in both A and B twice the respective radius, that is, it is the respective diameter. Calling v_a the rate of progression in A, and v_b that in B, we have therefore

$$\frac{N_a}{N_b} = \frac{\dfrac{v_a}{d_a}}{\dfrac{v_b}{d_b}} = \frac{v_a d_b}{v_b d_a}$$

$$\therefore \frac{v_a d_b}{v_b d_a} = \frac{\sqrt{d_b}}{\sqrt{d_a}}$$

$$\therefore \quad \frac{v_a}{v_b} = \frac{\sqrt{d_a}}{\sqrt{d_b}}$$

or the rates of progression are directly proportional to the trough diameters, that is to the wave-lengths. It appears from experiments of this nature that a wave 1 meter in length will travel in open water almost exactly 83 meters in a minute, or about 3 miles in an hour. Of course in open water the moving water has to set a larger and larger ring of water in motion as the circle increases. The wave loses in amplitude as it spreads. It also appears to gain a little in length. The latter point requires examination.

The rate of recurrence of the same phase in the same place, which may be called the rate of pulsation, depends of course on, and is the same as, the rate of swing to and fro of each particle. Each particle is virtually a pendulum, but only those symmetrically situated move in equal or indeed similar arcs. Still the same relationship exists with the wave as with the pendulum; for the rate of swing of the latter also, that

is, the number of times of its reappearance in the same phase in the same place, is inversely as the square root of its length. The relationship is still more close. If a pendulum be taken whose vibrating length is exactly the radius of the circular trough, the pulsating water and the swinging pendulum will keep exact time with one another if the swing of the pendulum be small. Further, all liquids give rise under like conditions (of wave-length) to waves which travel at the same rate whatever be the densities of the liquids: just as all pendulums swing at the same rate whatever be their weight, if they are of the same length.

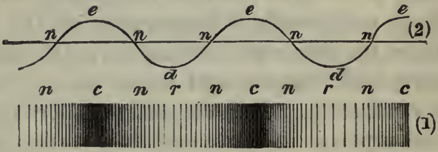
§ 79. **Waves governed by elasticity.**—In all other wave systems the elasticity of the matter in which the wave travels takes effect, for in all other systems change of volume accompanies the wave in its motion. This is true as well when a wave of transverse displacement travels along an elastic rod or cord as it obviously is when the particles move in succession to and fro longitudinally, that is, in the same direction as the wave itself moves, either in solids, liquids, or gases.

In the latter case indeed the wave may well be called a wave of change of density; and as elasticity varies with density, it may also be called a wave of elasticity. Such waves travel so fast that their rate of motion can only be got at either directly by taking great lengths of them, or indirectly by finding the number of recurrences of the same phase in a given time. And this is again generally measured by the varying physiological effect on the perception when the drum of the ear receives various numbers of pushes and pulls in

a given time, and so communicates sensations of notes of different *pitch*, that is, shriller or graver notes. Perhaps the simplest conception of the formation of an air wave system from a solid is to imagine a sphere surrounded by air, and to suppose the sphere to swell and shrink alternately,—alternating spherical concentric shells of condensation and rarefaction would be thrown off. All particles at the same distance from the sphere would be in the same phase at the same time. As a result of experiment it is found that at the end of the first second the first shell would be at 1,100 feet from the sphere, and there would be as many shells of compression as the number of times the sphere had swollen during the second. Alternating with these would be as many spherical shells of rarefaction. Each air particle moves fro and to as it takes part in the wave motion, in a straight line radial to the shells. A particle begins to move when the front of the shell of compression touches it, and it completes its motion when the back of the next shell of rarefaction leaves it. Accordingly, an air wave, like a water wave, travels its own length in the time that a particle occupies in going through all its changes of position, so as to be ready to start again in the same direction. The length of an air wave is the distance between any two particles in the same phase: from one place where there is maximum density to the next, or from one place of minimum density to the next, or from any other place of given density to the next but one. There is thus a very great analogy between an air or sound wave and a water wave, as fig. 37

shows, where in (1) the closeness of the lines represents the closeness of the particles of air which are made to correspond with the elevations and depressions in (2) which represents wave system of elevation and depression. It is clear that if all air waves travel at the rate of 1,100 feet a second, and there are n waves started in a second, the whole air space within a radius of 1,100 feet will at the end of a second consist of n shells of condensation alternating with n shells of rarefaction all at equal distances apart. In other words,

Fig. 37.



there will be n waves in a radius of 1,100 feet. Each wave will be therefore $\frac{1100}{n}$ feet long and universally

$$\text{wave-length in feet} = \frac{\text{no. of feet wave travels in 1 second}}{\text{no. of waves generated in 1 second.}}$$

The amplitude of an air wave is the greatest distance between two positions of one and the same particle. The *vis viva* of the air wave has to be exerted on a greater and greater mass as the wave spreads, and accordingly the amplitude diminishes. Air waves are audible when the amplitude cannot be more than $\frac{1}{10,000,000}$ of an inch. A system of sound

waves slightly increases in wave-length as the wave radiates.

§ 80. **Conversion of sounds into Notes.**—Without entering upon the anatomy and physiology of the ear, we may assume that an elementary sound is produced by a single air wave thrusting in and pulling out the drum of the ear. The duration in time of this excursion is the same as that of the excursion of any air particle. The extent of the drum's excursion depends upon the vigour (*vis viva*) of the blow it receives ($\frac{1}{2}mv^2$). And the loudness of the sound is not necessarily proportional to the vigour of the blow, nor to the extent of the drum's excursion. Sounds are seldom simple in their origin, and even when they are so, echo and the reverberation of surrounding bodies generally prolong the sound and alter its character. But even a single air wave produces a sensory effect which endures after mechanical action has ceased for a time of about $\frac{1}{16}$ of a second. If a second similar sound is produced within this time interval, the sensations of the old and new sounds are continuous. If other similar waves succeed at the same small intervals, a continuous sound is produced, called a note. The quicker the sequence, the shriller the note, the higher its pitch: the slower the sequence, the graver the note, the lower its pitch. A large humming-top has a round-headed nail driven into its peg. The lower part of the upper stem is cut into a triangular prism, the upper part being thinned. Three circular discs of tin-plate have triangular holes in their centres, so as to fit on to the stem. One of these has two rings of holes, the

outer being twice as numerous as the inner. The two other discs are toothed, the larger having twice as many teeth as the smaller. The two can be placed together on the stem, the larger being below and the two being separated by a triangular washer. The top is filled with wet sand, and the hole stopped. The single perforated disc being slipped on the top is spun in the usual way on the bottom of a tumbler. Air is blown upon the two rings of holes in succession through a glass tube, the bent-down end of the tube being held as near as possible to the disc without touching it. A puff of air passes through each hole as it comes beneath the tube, and this momentary air-puff reaches the ear as a sound-wave. The puffs succeeding one another with greater rapidity than 16 in a second, a continuous note is heard which for the same ring of holes becomes graver as the top languishes, but is always for the outer ring an octave higher than for the inner ring. So when the two toothed rings are put on and the top spun, a card held in contact with the twice as numerously toothed disc gives always the note which is the higher octave of that given by the other disc. Both become graver as the rate fades. Hence it follows not only that a higher pitched note is the result of more frequent sound waves in the same time (and therefore shorter waves), but that what is known in music and recognised by most ears as the relation between a note

FIG. 38.

and its higher octave is the relationship between the impressions which n and $2n$ sound waves in the same space of time make upon the perception, or the relationship between the impression which a series of sound waves of length l and a series of length $\frac{l}{2}$ make upon the perception. Whether the feeling called pitch depends upon the appreciation of the rapidity of sequence or upon the duration of each distortion of the ear-drum is not easy to decide, for the one is the inverse of the other. Perhaps the fact that a single long wave produces a different impression from that produced by a single short wave, and that this difference reminds one of the differences between grave and shrill notes, may be regarded as evidence that duration of individual impression rather than rate of sequence is to be considered as the origin of pitch.

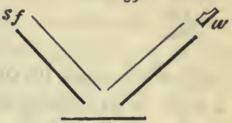
§ 81. **Detection of sound. Sensitive flame.**—In order to render visible facts connected with the reflexion, refraction, absorption, and dispersion of sound, use is made of the effect of the sound wave on fluid jets. Three kinds of jets are used. A liquid pouring in a smooth vertical jet from a cistern at such a slow rate that it is ready to break up into drops, will so break up if subjected to sonorous vibrations. A jet of air rendered visible by being charged with smoke becomes stunted under the same conditions. Perhaps the most striking and convenient is the sensitive flame. Coal gas is collected in a mackintosh bag provided with a stop-cock. The bag is placed between boards, which are so loaded that the elasticity is increased by about $\frac{1}{10}$th part. The gas is led to a

long straight burner, having an orifice of about $\frac{1}{20}$th of an inch. This will give a flame about a foot high and $\frac{1}{2}$ in. diameter. The stop-cock is turned on till the jet is on the point of 'flaring.' Most sounds and notes will, when not too far from the flame, cause it to duck down and flare. This is especially the case with sibilant sounds—hissing, crumpling, rustling, clinking, scraping, &c., all of which sounds consist of or contain high notes. Notes which are so high as to be inaudible to the ear affect the flame. For the flame to be affected it is necessary that if the jet be of rigid material, the orifice of it should be exposed to the beat of the waves.

§ 82. **Reflexion of sound.**—Let a sensitive flame be placed at one end of a metal tube 12 feet long and a few inches in diameter. Remove the pea from a dog-whistle, and sound the whistle at a distance of 12 feet. If the flame respond, diminish the supply of gas till it ceases to do so. Then bring the sounding whistle towards the other end of the metal tube. As it gets near the end, it will cause the flame to duck and flare, and when it is on the axis of the tube it may be some feet from it without ceasing to cause the same effect. Diminish the sensitiveness of the flame, so that when the whistle is sounded at the other end of the tube the flame remains tranquil. Place behind the whistle a parabolic or spherical mirror, so that the whistle is in the principal focus and the axes of the tube and mirror coincide. The flame again flares. Place a cloth between the whistle and the mirror, the flame is restored. To exhibit the law of reflexion of sound, namely, that the angles of incidence and re-

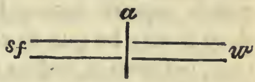
flexion are equal, and that the incident beam, the reflected beam, and normal to the surface at the place of incidence, are all in one plane, arrange two metal tubes, each about 4 feet long, horizontally (fig. 39), and at right angles to one another. Sound the whistle, *w*, and regulate the gas so that the flame, *sf*, is not affected. Then introduce at *a* a sheet of cardboard inclined at 45° to each tube; the flame flares. The hand placed at *a* also reflects the sound waves to *sf*. The flame of a flat fishtail burner produces the same effect, and so does even the sheet of heated gas from such a flame when the burner is placed somewhat lower down.

FIG. 39.



The absorption of sound is exhibited in a similar manner. The tubes are now placed in the same straight line, with their ends about an inch apart. The whistle is sounded uniformly, and the flame is so adjusted that it responds freely. A sheet of cardboard or paper, or a flat gas flame at *a*, cuts off the sound by reflexion. A single fold of a wet towel produces the same effect; while several folds of a dry towel fail to cut off the sound. The films of water in the wet towel being of different sizes, break up the waves they receive into waves of different sizes, and urge them in different directions. Through the dry towel the air is continuous, and part of the wave proceeds unbroken.

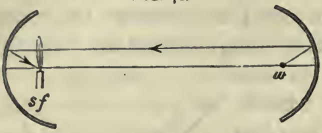
FIG. 40.



Perhaps the most complete arrangement for

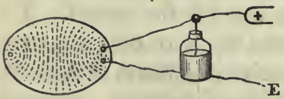
showing most facts connected with reflexion and absorption, dispersion, &c., is shown in fig. 41, where two spherical mirrors, about 18 in. in diameter, are placed

FIG. 41.



with their axes in one line, at a distance of about 4 feet. The whistle is supported in the principal focus of the one, and the sensitive flame in that of the other (the distance of the principal focus from the mirror is half the radius of the mirror, and it is measured once for all by finding where the image of the sun, or of a gas flame at a distance of 20 or 30 yards, is formed on a transparent paper screen). The flame is so adjusted that without the mirrors no effect is produced; also when only one mirror is in position. When both mirrors are in position the flame flares. This flaring is not prevented by placing a 2-inch square screen between *w* and *sf*, however close it may be put to either; but on placing it close to *w*, between *w* and its mirror, or close to *sf*, between *sf* and its mirror, the flame ceases to flare. The actual tracing of the sound-wave before and after reflexion is shown by the device in fig. 42. A perfectly flat and very smooth elliptical board, japanned, is surrounded by a smooth

FIG. 42.

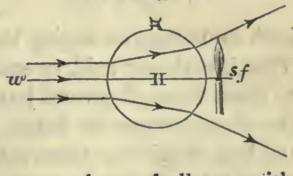


wall 2 or 3 inches high, the axes of the ellipse being as three to four. Two brass knobs are fastened above the board about $\frac{1}{8}$ in. apart, in such a way that the straight

line joining them is bisected by one focus of the ellipse. Dry lycopodium is scattered through muslin uniformly over the wood, and the whole is covered by a glass plate. One of the knobs is connected with the inner coating of a Leyden jar, the other with the outer coating and the earth. The inner coating of the jar is also connected with the prime conductor of an electrical machine. On turning the machine, sparks pass from knob to knob, giving rise to sound waves. These waves are reflected, and converge to the other focus. The lycopodium is found to be arranged in two families of concentric circles around the foci. Strictly speaking, we do not get here a tracing of a moving wave; for a moving wave can leave no tracing of accumulation, because each particle moves equally in its turn. What we find is the tracing of a system of stationary waves, due to the interference of the echo waves with the original waves.

§ 83. **Refraction of sound.**—As a ray or beam of light on passing from an optically rarer medium to an optically denser one is bent towards the normal at the point of impact, so a beam of sound in passing from a lighter gas to a denser one is bent in the same way. If it passes into a lighter gas, it is bent away from the normal. It is possible to construct gas sound lenses on this principle. Let a whistle, *w* (fig. 43), be at such a distance from the singing flame, *sf*, as just to affect it. Fill a toy caoutchouc balloon with

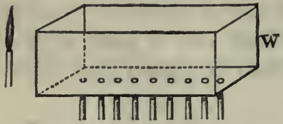
FIG. 43.



air, and hold it close to the flame; the flame still flares. Fill a similar balloon with hydrogen, and place it in the same position; the flame ceases to flare, because the balloon acts then as a dispersing lens. Remove the balloon, and reduce the gas so that the flame ceases to flare, then introduce a similar balloon in the same place filled with carbonic acid; the flame now flares, because the balloon acts as a condensing lens.

It is well known that sound travels with less loss through air of uniform density than through a heterogeneous atmosphere. This appears to be the reason why sounds are heard distinctly in frosty weather, where by contact with snow or ice-cold ground the air is of a pretty uniform temperature, and contains the same amount throughout of aqueous vapour. Also when the air is throughout of the same temperature and saturated with moisture, as after a shower of rain, sounds are distinct. The obstruction of mist particles to sound is not so hostile to its clearness as variation in density. This is shown experimentally by placing the sensitive flame at one end (fig. 44), and the whistle at the other end of a long box open at both ends, and arranging the flame so as just to flare. Then if carbonic acid, or steam, or coal gas be allowed to enter through several jets in the bottom of the box, the flame ceases to flare. If coal gas is employed, the box should be tilted a little upwards towards the whistle, to prevent an explosion.

FIG. 44.



ORIGINS OF SOUND WAVES.

§ 84. **Transverse vibrations of rods.**—If a square rod is fastened rigidly at one end, and plucked at the other end, it will swing backwards and forwards at a certain rate, and if it be not plucked too far, its rate of swinging is the same, whether its excursion be great or small. The rate of swinging, that is, the number of swings to and fro, depends upon the elasticity of the rod, upon its density, and also upon its length and thickness in the direction of swing. If we are considering rods of the same material, and examining them at the same time, density and elasticity are out of count, because they are constant. It is found that if n be the number of vibrations to and fro in a given time, l be the length of the rod, and t its thickness in the plane of vibration,

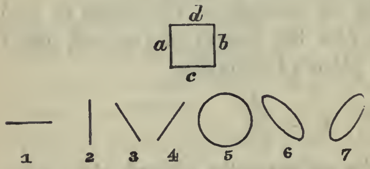
$$n \propto \frac{t}{l^2}$$

To prove this, take a carefully planed deal rectangular rod, 1 in. wide, $\frac{1}{2}$ in. thick exactly, and about 12 ft. long. Clamp it firmly between cardboard in a vice horizontally, and so that its $\frac{1}{2}$ in. faces are horizontal, and so that 10 feet are free. Set it swinging gently horizontally. It will hang down in a curve, but this does not matter. Adjust a leaden bullet at the end of a silk thread, so as to swing at the same rate as the rod. Adjust another such pendulum to swing twice as fast as the first. Now shorten the rod till it swings at the same rate as the second pendulum: on measuring the rod it is found to be about 7 ft. long.

$$n_2 = 2n_1, \quad \frac{1}{l_2^2} = 2\frac{1}{l_1^2}, \quad \frac{1}{7^2} = 2\frac{1}{10^2} \text{ nearly.}$$

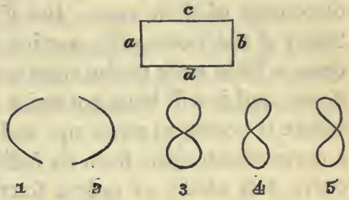
This shows that the number of oscillations varies inversely with the square of the length. Now return to the 10 ft. length, but turn the rod, so that the 1 in. faces are horizontal. It will now be found to swing with the shorter pendulum, that is, twice as fast as it did when, being of the same length, it was of double thickness in the direction of swing. Accordingly, if we take a nicely-worked square steel rod, and clamp it at one end rigidly, and furnish the top with a bright bead, so that, by the retention of images, the reflection of a flame in the bead appears as a streak of light, we shall get a line of light (1) if the rod is plucked from *a* to *b*, also a line (2) if it is plucked from *c* to *d*; it will trace out the line (3) if plucked simultaneously from *a* to *b*, and from *d* to *c*; the line (4) will be shown if it be plucked simultaneously from *b* to *a* and *d* to *c*. If in case (2) when the point has performed a quarter of its path, the rod receives an equal blow from *a* to *b*, it will travel in a circle (5). If it receive such a blow when it has nearly completed its (2) motion, it will trace out the ellipse (6). If it receive the blow soon after starting, it will describe the ellipse (7). In the cases (3), (4), (5), (6), (7), where both motions are imparted, it is seen that a point moving along the curve, or up and down the line, moves as often up and down as to the right and left.

FIG. 45.



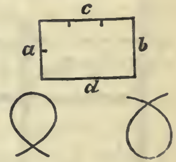
If (fig. 46) the rod be twice as thick one way as the other, and it receive simultaneous impulses from *d* to *c* and from *b* to *a*, it will swing to the left and back again while it is moving up (in the figure), and to the left and back while it is moving down, and so trace out (1). If it receives simultaneously an impulse from *d* to *c* and an impulse from *a* to *b*, it will, for similar reasons, trace out the curve (2). If, when, by reason of the impulse from *d* to *c*, it has got half up, it receives an impulse from *a* to *b*, it will describe the figure of 8, (3): (4), and (5) show the curves traced out, when the *a b* impulse is imparted at different phases of the *c d* motion. In all cases, a point passing along these curves travels twice as often to the right and left as up and down.

FIG. 46.



If the width of the rod be to the breadth as 2 to 3, figures must be formed of such a kind that a point moving over them passes three times from left to right and back while it passes twice up and down. These conditions will be seen to be fulfilled by figures of which types are shown in fig. 47.

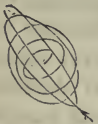
FIG. 47.



Other ratios, such as 3 : 4, 3 : 5, 4 : 5, &c., give characteristic figures of more complex shape. As the vibrations die out the point of the rod makes shorter and shorter excursions in both directions. So that, for instance, in the first case, with

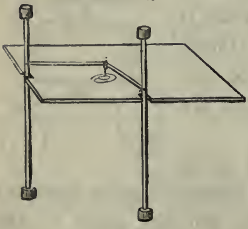
the square rod the lines (3) and (4) become shorter, (5) becomes a circular spiral, and (6) and (7) become elliptic spirals preserving their eccentricity and the directions of their axes. But if *a b* be a little longer than *c d* the point will, starting from case (3), have come a little back to the right before it begins to move down, and it will have got twice as much to the right before it begins to move up, and so on. It will form a curve which apart from its fading off is not a closed curve, but which, as only a fraction of it is visible at once, changes in aspect from (3) to (6), from (6) to (5), from (5) to (7), from (7) to (4), from (4) to (7), to (5), to (6), to (3). So when the dimensions are as 2 : 1 (fig. 46), if there be a little defect in the ratio, the figure will pass from (1) to (4), to (3), to (5), to (2), to (5), to (3), to (4), to (1). And so for other cases. If both defect in ratio and fading off occurs, a spiral is traced, out of which an idea is given in fig. 48.

FIG. 48.



§ 85. These figures can be imitated artificially, and the whole course of the point registered graphically, by pivoting two pendulums to two adjacent sides of a square table, and fastening with some vulcanised caoutchouc joints two arms to the upper parts of the pendulums at right angles to one another in a horizontal plane. The ends of the arms are also joined together by a ball and socket joint or by a Hooke's

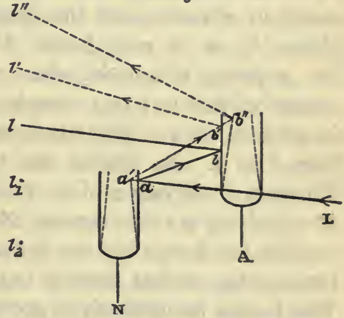
FIG. 49.



joint. This joint carries a vertical glass tube pen charged with aniline colour, or a style to scratch lampblack off smoked glass.

Use is made of the constancy of these figures or the reverse to test the consonance of tuning-forks, and to make one fork either be in perfect unison with another, or at a known interval from it. Thus to adjust a fork to be in unison with the fork N, a beam of light, L (fig. 50), is thrown upon the polished face of one prong of N which is vertical, thence it is reflected and strikes the polished face of one prong of A, thence it is reflected and falls upon a screen at *l*. If, however, the prongs of N are bent in, as the dotted lines represent, the light strikes with a greater incident angle at a', is reflected higher on the prong of A, and reaches the screen at l'; when the prong of N is bent outwards the light will be reflected to l_1, so that as the prong moves in and out the spot of light travels rapidly from l' to l_1 and back, forming a vertical streak. If A be bowed at the same time and its prongs are bent inwards at the same time as those of A, the light reflected from a' will strike the fork A at b' with greater incidence than before, and the ray will be reflected to l''. When the prongs of both forks are bent outwards the light will

FIG. 50.



appear at l_2, so that when both forks are sounding, a streak of light extends from l'' to l_2. Suppose now the fork A to be a little out of tune, and to be a little too high or swift in its vibration, the reflecting prong of A will have come a little back when the prong of N has reached the end of its excursion, so that the light will fall a little lower than l'. When the N prong is bent outwards, the A prong will be twice as much in advance, and the spot will be twice as far above l_2 as it was below l'', and so on, until the A prong is upright, when N is at its maximum excursion, that is, $\frac{1}{4}$ of a complete vibration *to* and *fro*, in advance of N. The streak of light will then reach from l' to l_1. In double the time A will be half a vibration in advance of N, that is, when the prong of N is bent in to its utmost, the prong of A is bent out, the last bends the ray down as much as the first bends it up, so that there is only a spot of light at l. This begins immediately to grow until A is a complete vibration in advance of N. The forks are now again in the same phase, and the maximum length of streak is obtained. To bow a fork without stopping it or altering its phase, the bow is made to touch the fork with a sliding motion. The shortening and lengthening of the line of light (which is easily distinguished from the shortening due to languishing, for the latter is not followed by lengthening) takes place the more quickly the greater the disagreement between the forks. To see whether the fork A is too fast or too slow, for the effect on the light line would be the same, one prong of A is loaded with a little wax containing a swan shot. If this makes the gaping of the

line more rapid of course the fork was already too slow, for loading diminishes the rate. If loading makes the gaping of the line less rapid, the fork A is too quick; in the former case metal is filed off the upper part of the prongs, for this unloads them without diminishing the elasticity. In the latter case metal is filed off the root of the fork, for this diminishes the elasticity without sensibly affecting the inertia.

For other ratios besides 1 : 1, as when we wish to adjust a fork so as to be the higher octave of the fork N, one fork, say N, is clamped vertically as before, and this alone would give a vertical streak. The fork to be adjusted is clamped horizontally with its polished face vertical. This alone would give a horizontal streak. When the two forks are sounded together, if their rates are nearly in the ratio of 1 : 2, a curve of light resembling one of those in § 84 will be formed, and this will pass more or less rapidly through the figures (1) (4) (3) (5) (2) according as the octave-harmony is less or more perfect. As before, loading the fork shows whether it is too fast or too slow, and it has to be filed as before till one of these forms remains constant for a long time. If it takes a minute for the figures to pass through all shapes and return to its original shape, this means of course that the fork A in a minute gives one vibration more, or one vibration less than twice the number made by N in a minute. So that if N gives 520 complete vibrations in a second or 31,200 in a minute, A gives 62,399 in a minute or 1039·983 in a second instead of 1040· which is the higher octave of N. This to the ear would be perfect harmony.

§ 86. **Transverse waves in strings. Nodes. Stationary waves.**—Take three similar vulcanised caoutchouc tubes each twelve feet long. Let two be empty: fill the third with sand and tie up its ends. Fasten the three side by side at one end about 12 feet from the ground and hold the other ends so that the tubes slant. Stretch one of the empty tubes two or three feet. Hit it near the holding hand downwards at right angles to the tube. A depression or valley travels to the upper fixed end and being there reflected returns as an elevation (the reflected valley of the water wave returns as a valley, § 77). And if an elevation be sent it returns as a depression. On whatever side the tube is struck the half wave returns on the opposite side. It will be noticed that it is impossible to send a pure half wave because the recoil of the tube near the fixed hand sends a displacement following the chief one on the opposite side. Holding the lower end move it now rapidly once up and once down and bring it to rest. The complete wave will be reflected and reach the hand inverted, valley first; on reflexion from the hand it will again move as at first: and so on till by the internal friction and the resistance of the air it dies away. Next examine two empty tubes side by side. Stretch them equally and hit them simultaneously and at equal distances from the ends, but with unequal vigour. The greater displacement of the one and the lesser displacement of the other travel at the same rate and after reflexion reach the hand at the same moment. The rate of progression of waves maintained by elasticity is independent of amplitude and

wave-length (gravity or water waves vary in rate directly as the square root of their length, § 77). Next let one tube be stretched more than the other, but equal lengths of them taken. On striking them both simultaneously the wave in the more stretched tube travels the faster, and the more the tube is stretched the greater the rate. This increase of rate is due to two causes, the increased elasticity and the diminished thickness or mass. To get the effect due to elasticity or stretching alone, take two tubes of unequal diameter. Weigh equal weights of them and stretch them anyhow so that their lengths are equal; their diameters are then equal and every unit of length of the one has the same mass as a unit of length of the other. The tube which was originally the thickest will be stretched the most, and the wave will travel down it the fastest.

Next compare the tube loaded with sand with an empty tube of the same tension and length. It will be seen that the wave travels down the heavy tube much slower than down the light one, and in order to make the rates of progression equal the heavy tube has to be considerably stretched.

$$v \propto \sqrt{\frac{s}{m}}.$$

Fasten now one end of the sand-filled tube to the wall and fasten an empty tube to its lower end. On sending a vigorous wave down the empty tube, a part of it is reflected inverted from the end of the heavy tube, but a part enters the sand tube as a wave of diminished amplitude and velocity. This wave is

reflected from the fixed end, returns reversed and bursts into the empty tube with increased velocity and amplitude.

If we take one of the above tubes and by a motion of the hand send a series of complete waves down it of such a length that, when the front of the reflected first elevation (in the form of a depression) has reached the middle, the front of the second elevation reaches the middle coming in the opposite direction, the middle point will be pushed up and down at the same time with the same pressure and will remain at rest. When this second elevation has reached the end the reflected first elevation has reached the beginning. It is seen that each contour of the cord, 1, 2, 3, is a complete wave, so that the wave-length is equal to the length of the cord. Now the point m being always at rest because it is always subjected to equal and opposite pressures may be considered rigid. That is, instead of one cord vibrating in two segments with a node between, one segment moving up as the other moves down, we may consider each half by itself moving up and down between two fixed points. It will keep the same time as the two together. The length of the cord is now only half the wave-length.

FIG. 51.

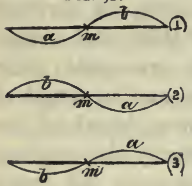
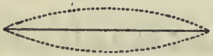


FIG. 52.



Now (comp. § 77) the

$$\text{number of vibrations} = \frac{\text{velocity}}{\text{wave-length.}}$$

and since

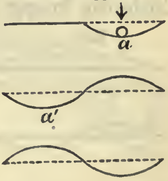
$$v \quad \sqrt{\frac{s}{m}}$$

it follows that if l be the length of the cord

$$n \propto \frac{1}{l}\sqrt{\frac{s}{m}}$$

Though thus derived from the advance and reflexion of two elevations or depressions, we may pluck the middles of the two halves, the one up and the other down, simultaneously and observe the segmental vibration with the central node. So when the cord vibrates as a whole, being plucked in the middle, we may, if we choose, regard its two halves as being reflected from the two fixed ends. Although above (p. 90) we neglected the automatic depression which accompanied the elevation, when the end is rigidly fastened this depression or reflexion from the beginning is of absolute importance. Thus when a wire is struck at a quarter its length from one fixed end, its successive conditions are shown in fig. 53. That is, while part of the stored energy of the displaced segment determines the progression of the depression to a', the other part carries the segment back across the normal line producing an elevation.

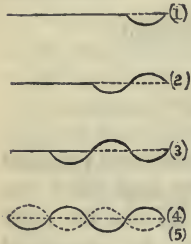
FIG. 53.



§ 87. With the elastic tube one can study the growth and establishment of such segmental vibrations or stationary waves. Taking one of the elastic

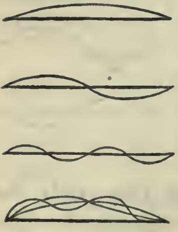
tubes move the hand quickly to and fro and by and bye the cord and the hand will fall into one another's humour and the cord will fall into segments separated by nodes.

Fig. 54.



The rate of vibration of the segments is inversely proportional to their lengths, that is proportional to their number. That such segmentary vibration when once established is automatic is shown by rigidly fixing an elastic tube in a vertical position and while gently restraining (damping) the middle by letting it pass between the fingers, plucking the middle of one-half. The tube being released vibrates in two segments with a central node. Damped at one-third and plucked at one-sixth from the bottom it vibrates in three segments and so on. In this experiment it should be remembered that the upper part of the tube has a little the greater tension, so that the upper segment to be synchronous with the lower segment should be a little the longer : and so for the other cases.

Fig. 55.



§ 88. By the elastic cord it can be shown that a string may vibrate as a whole and in segments at the same time provided there is always either an odd or an even number of automatic nodes : and in all cases however it may be vibrating in segments it can vibrate as a whole.

The nodes on wires are well shown by stretching

a wire several feet long horizontally and dividing it into eight equal parts by seven stirrups of paper resting on the wire. The second stirrup from one end is gently pinched around the wire and the wire is gently plucked where the first stirrup rests. The 3rd, 5th, and 7th stirrups will be jerked off, for they are at the centres of segments; the 4th, 5th, and 6th will retain their places, for they are at nodes.

§ 89. **Vibrating strings as sources of sound.**—The conditions which determine the rate of vibration of a stretched string or wire are, as we have seen, the stretching pressure or weight hung at one end, the length and the mass

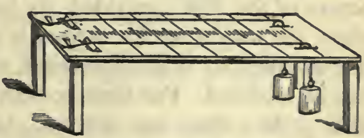
$$n \propto \frac{\sqrt{s}}{l\sqrt{m}}$$

or in an unloaded string since $m \propto d^2$ if d be the diameter, for the same material

$$n \propto \frac{\sqrt{s}}{ld}$$

Steel wires (pianoforte wires) are the most convenient for studying this relationship. A table (fig. 56) has two iron pegs driven obliquely in at one end. At the other end are two pulleys let into the table so that their axes are on the table. Two mahogany wedges nearly of the same height as the pulleys, are permanently fixed at the same distance from the pulleys, so that measured

Fig. 56.



from the top of the wedge to the top of the pulley there is a whole number of units of length, say 64 in. Two other movable wedges or bridges a little higher than the fixed ones are provided, and the table is divided into inches numbered from the axes of the pulleys. The wires being horizontal the vibrating length is the distance from the top of the pulley to the top of the bridge, or from the axis of the pulley to the centre of the base of the bridge. Let wires of the same metal and the same gauge be fastened to the pegs and passed over the pulleys. Bring the movable bridges to any the same distance from the pulleys, say 18 in., and hang a weight of say 10 lbs. at the end of one wire, and also 10 lbs. at the end of the other. The two wires are perfectly identical and under identical conditions: plucked gently and in the middle they will give identical notes. Weight now one of the wires, further. Its note will rise in pitch till it is weighted with 40 lbs., whereupon it will give out the easily recognisable higher octave of the other wire. And so, whatever be the weight or stretching pressure on the first wire, and whatever its length, the second will give the higher octave of the first, provided its length is the same, when the weight on the second is 4 times as great as that on the first. With short wires, say 1 foot long, this can be repeated. For suppose both wires are stretched with 5 lbs., then one with 20, then the first being stretched by 80 lbs. will give the higher octave of the second, or the second octave above its original note, that is 4 times its original number of vibrations.

Birmingham steel wire of 14 gauge will easily bear a strain of 112 lbs. if there are no kinks in it. Such

experiments, and they can be multiplied without limit, prove that $n \propto \sqrt{s}$.

Start with the wires of equal length, stretched with 10 and 40 lbs. respectively, then move the bridge of the first wire till the length of that wire is halved. The notes will now be in unison, showing that halving the length, other things remaining unchanged, has doubled the number of vibrations. Or start with two wires of the same length, stretched with 5 and 80 lbs. respectively, so that the second gives four times as many vibrations as the first and move the bridge of the 5 lb. wire till its length is only one quarter of that of the 80 lb. wire, unison is restored. These experiments prove that $n \propto \frac{1}{l}$. Both these relationships can be elegantly verified in the following manner. Put the bridge of the one wire at any whole number of inches, say 30, and fasten to the wire a known weight, say 56 lbs. Hang from the other wire an unknown weight in a bag. Move the bridge of the second wire till there is unison. Suppose this distance be found to be 24 inches. Then, since there is unison, if x be the unknown weight—

$$\frac{\sqrt{56}}{30} = \frac{\sqrt{x}}{24} \text{ or } \frac{56}{900} = \frac{x}{576} \text{ or } x = 35{\cdot}86 \text{ lbs.}$$

On actually weighing the bag of weights the result agrees generally within one or two ounces.

To confirm the relationship $n \propto \frac{1}{d}$, it is necessary to determine d with great accuracy, or rather to compare accurately the diameter of one wire with that

of the other. This is best done by measuring exactly equal lengths of the two wires and weighing them, the weights being w_1 and w_2, then $\frac{d_1}{d_2} = \frac{\sqrt{w_1}}{\sqrt{w_2}}$. Let two such wires be of equal length, vary the stretching pressure on one till there is unison. It is then found that the square roots of the stretching pressures are directly as the diameters, or the stretching pressures are directly as the weights of the wires—

$$\frac{\sqrt{s_1}}{\sqrt{s_2}} = \frac{d_1}{d_2} \text{ or } \frac{s_1}{s_2} = \frac{{d_1}^2}{{d_2}^2} = \frac{w_1}{w_2}.$$

Or, taking equal stretching pressures, vary the lengths till there is unison, it is then found that the lengths are inversely as the thicknesses $\frac{l_1}{l_2} = \frac{d_2}{d_1}$, or the square of the lengths inversely as the weights $\frac{{l_1}^2}{{l_2}^2} = \frac{w_2}{w_1}$. The relative diameters of dissimilar metals are obtained by weighing equal lengths, taking the square roots of the weights, and dividing by the specific gravities.

§ 90. **Musical scale.**—The scale most generally in use is formed as follows. Let a note consist of n vibrations a second. Then—

Note Tonic	Second	Major Third	Fourth	Fifth	Major Sixth	Major Seventh	Octave
n	$\frac{9}{8}n$	$\frac{5}{4}n$	$\frac{4}{3}n$	$\frac{3}{2}n$	$\frac{5}{3}n$	$\frac{15}{8}n$	$2n$.

Sometimes the 'middle C' is taken as having 256 vibrations a second; the eight complete notes from this C to its higher octave are—

C	D	E	F	G	A	B	C′
256	288	320	341·3	384	426·6	480	512.

Whole numbers are obtained throughout if, as is sometimes done, 264 vibrations are given to C—

C	D	E	F	G	A	B	C′
264	297	330	352	396	440	495	528.

Suppose therefore we have a wire stretched over a board between two pegs, one of which is fixed and the other has a hole in it through which the wire passes, and suppose we have a bridge at a distance l from the peg with the hole. The latter can be turned round with a key if it has a square head until the length l is in unison with a C tuning-fork. Divide the distance l into lengths, namely—

C	D	E	F	G	A	B	C′
l	$\frac{8}{9}l$	$\frac{4}{5}l$	$\frac{3}{4}l$	$\frac{2}{3}l$	$\frac{3}{5}l$	$\frac{8}{15}l$	$\frac{1}{2}l$.

Then the bridge being placed at one or other of these places, the wire will give the corresponding note. Such a wire with its scale is a *monochord*.

In the harp, pianoforte, and other stringed instruments, the number of vibrations per second which each string gives is determined partly by the string's length, partly by its weight, and partly by its tension. That is, the strings producing the higher notes are not only the shortest; they are the thinnest and are stretched the most. The wires of the graver notes are loaded with spirals of thin wire. To avoid 'thinness' of sound, which accompanies thin, short, highly strung wires, several, two or three, similar wires are placed side by side and struck by the same hammer.

This enriches the note. The 'tuning' is always effected by varying the tension, that is, turning one of the pegs to which the wire is fastened. The hammer is not applied at the centre of the wire so as to sound only the fundamental note, but at such a distance from the end that besides the fundamental note harmonics are sounded as well, which enrich the sound, without, to most ears, impairing its purity.

§ 91. **Further development of nodes.—Nodes in rods.**—In § 84 we considered the note of a rod vibrating as a whole, and found that the rate of vibra- on varied inversely with the square of the length.

FIG. 57.

A longish rod or wand may be easily shaken at one end so as to divide itself into two parts, a segment and half a segment, separated by a node rather less than one-third from the free end. By a more rapid motion two segments and a half may be got, there being then two automatic nodes, one at nearly one-fifth and the other at nearly three-fifths from the free end. As the segment and the free part vibrate at the same rate, the rate of vibration of the whole may be very roughly considered as the rate of the half segment at the end, that is the rate of a rod of length $\frac{1}{3}l$ fastened at one end. Since the number of vibrations varies inversely with the square of the length, the number of vibrations of the fundamental note being n, the number now is $9 \times n$, and if there are two nodes it is $25 \times n$ and so on. These are the first and second harmonics. The nodal line can be traced on a tuning-fork when it is sounding its first harmonic by holding

it horizontally with the broad face of the prongs horizontal, scattering sand on both prongs and bowing near the root of the fork. All the sand except that which is over the nodal line is thrown off.

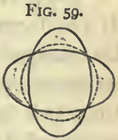
If we hold an elastic rod in the middle and move the middle transversely to and fro, the rod will fall into one whole and two half segments, separated by two automatic nodes; the rate of vibration in this case must be 16 times as fast as that of the fundamental note. The nodes are each at $\frac{22}{100}$ths of the length of the rod from its ends.

FIG. 58.

A strip of glass laid on two parallel threads at the distance of the nodes apart and lightly fastened to the threads gives off a highly clear note when struck in the middle. It is the note of the 'musical glasses.' In order to get the gamut of the musical glasses, if the length of the first glass is l_1, that of the second must be $l_1\sqrt{\frac{8}{9}}$, that of the third $l_1\sqrt{\frac{4}{5}}$, and so on (comp. § 90). Strips of glass of these lengths being cut, they are supported at a quarter their lengths from their ends on strings and form a scale of whole notes.

§ 92. **The Bell.**—If we hold a circular elastic hoop on two opposite sides and bend it in and out rapidly, we find that at four points there are nodes, and between them segments (quadrants) which move in and out, the points of maximum motion being four in number and situated midway between the nodes. Such is the motion of a bell when sounding its fundamental note. This is shown by employing an inverted bell or goblet and bowing it. If while it is sounding a little pellet of wax hung

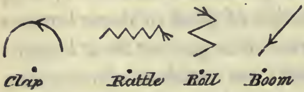
FIG. 59.



from a thread is carried round the edge outside so as always to lean upon the goblet, it is thrown off with violence where the goblet was bowed, and also at the opposite region, and also at quarter circumference distance from these points. But at the intermediate points, $\frac{1}{8}$ circumference distance from these, the pellet remains comparatively at rest. If the goblet be filled with water and then bowed as before, the water is thrown into great commotion at the bowing place and quadrant distances from it, but at the nodes it remains more tranquil.

The note given out by a drum depending upon the vibration of a membrane is seldom pure; the membrane breaks up into independently vibrating pieces according to the place where it is struck. The clash and clang of cymbals and the rattling boom of a gong are characteristic of the variety of air waves to which they give rise. The clap, rattle, roll and boom of thunder denote the course of the lightning flash and its attitude towards us.

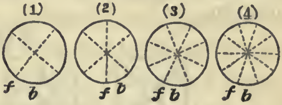
FIG. 60.



§ 93. **Nodes and segments in vibrating plates.**—If a uniform circular brass plate about 1 foot in diameter be clamped by a screw in the middle, it can be made to break up into any even number of sectors greater than two and maintain its own vibration, giving out notes of higher pitch according as the number of sectors is greater. These sectors so pulsate that when one is moving in one direction the two neighbouring ones are moving in the opposite. The sectors are separated by radial nodal lines upon which

strewn sand accumulates when the plate is sounded, thus tracing out the position of the nodes.

Fig. 61.



The formation of these lines is assisted by gently pressing the plate with a point where the node should meet the circumference. Thus in (1) the plate is bowed at *b* and the finger *f* touches the plate at $\frac{1}{8}$th of the circumference from *b*. The plate gives out its lowest or fundamental note. In (2) the finger is placed at $\frac{1}{12}$th the circumference from *b*, in (3) at $\frac{1}{16}$th, in (4) at $\frac{1}{20}$th, and so on. At the beginning of the stroke the bow should be pressed firmly and moved slowly across the edge at an angle of about 80°. As soon as the plate begins to speak a lighter and more rapid stroke is given.

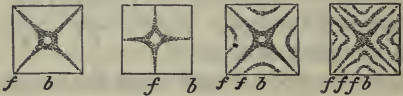
§ 94. If a round glass plate be clamped at a distance of $\frac{1}{3}$rd its radius from its edge, and a bundle of well resined horsehairs be drawn with lateral pressure through a small hole in the middle (fig. 62) the sand collects in a ring at one-third the radius from the edge. The vibration of a round plate and the vibration of a rectangular plate in § 91 are the counterparts of the water mononodal undulation in a cylindrical trough and the binodal undulation in a rectangular trough (§§ 77, 78).

Fig. 62.

§ 95. With a square plate clamped in the middle an almost endless variety of segmental vibrations and corresponding sand-marked nodal lines can be formed. It will be noticed, and is indeed an essential condition of all free vibration, that the number of vibrating

elements is even, and that all symmetrically situated elements are, at the same time, in the same phase of motion.

FIG. 63.



These figures can be rendered permanent by unscrewing the nut which secures the plate in the middle, and pressing upon the sand figure some gummed cardboard.

§ 96. **The Gas-wave.**—That continuity of matter is essential for the production of sound is shown by setting a hammer to strike a bell under the exhausted receiver of an air-pump. If the hammer and bell be hung or supported by non-resonant matter, the vibrations of the bell are almost inaudible. If, instead of air, hydrogen be admitted into the vacuum, the vibrations continue to be almost inaudible. For even when the tension inside the receiver is restored, the blow which the lighter gas (which is only $\frac{1}{14 \cdot 5}$ as dense as air) gives to the glass of the receiver is unable to communicate so much motion to it, as, when communicated to the outer air, suffices to give rise to an audible sound wave. (Compare empty and sand-loaded tubes, § 86.)

In the preceding §§ we have examined the production of sound, that is, air waves, by the vibration of rods, strings, membranes, plates, &c., and it is rare that a sound wave is neither started nor controlled by solid matter. The singing of a kettle depends indeed

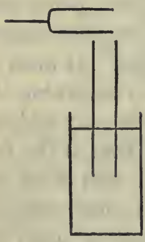
upon the collapse of strings of steam bubbles in water, and a few other instances may be adduced: but it not unfrequently happens that, although solid matter determines the sound wave, it does not itself participate in the motion its presence causes. Pure wind instruments, as the flute, are examples of this. It must be allowed that there is great ignorance concerning the motion of the air at the mouth of a tube over which a lateral current is passing. It appears that at the first instance air is caught by the edge and sent down the tube as a condensation. This returns after reflexion from the bottom at an interval dependent upon the length of the tube, reappears at the mouth as a condensation, and passes out of the mouth pushing away the air current. The wave of condensation, however, on leaving the tube's mouth, leaves a region of rarefaction behind it into which the air current is pushed. The latter again partly enters the tube, and sends down it a wave of compression. There is accordingly a kind of vibration of the air current towards and away from the tube's mouth, which vibration is governed by the time required for the wave to travel to and fro in the tube.

Accordingly of two tubes closed at the bottom, one of which is twice as long as the other, the longer will give the lower octave of the shorter, that is, a wave system of twice the length, of double the time interval, of half the rate of recurrence (pitch).

§ 97. Let us confirm this as follows. Take any tuning-fork the number of whose vibrations per second is known, say C, which makes suppose 256 complete vibrations in a second. From § 79 it appears that

$$\text{wave length in feet} = \frac{\text{no. of feet travelled in 1 second}}{\text{no. of waves generated in 1 sec.}}$$

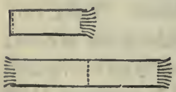
Fig. 64.



In this case therefore $= \frac{1100}{256} = 4$ ft. 3·6 in. Take now a tube open at both ends and about $\frac{1}{2}$ inch diameter, plunge the lower end into water, and holding the sounding fork above it move the tube up and down till the sound of the fork is greatly and suddenly increased. Measure the length of the tube from the open end to the level of the water, and it will be found to be about 1 foot 0·9 in. Cut eight or ten tubes of exactly this length, and grind their ends flat on a wet sandstone or the side of a grindstone. Prepare some glass, metal, wood, or cork discs the size of the outside measurement of the tube, and some pieces of vulcanised caoutchouc tubing about 1 in. long and rather less in diameter than the tubes. When such a disc is inserted into the caoutchouc and the latter is drawn on to the glass tube, the tube is of course closed at one end. Two tubes joined by a piece of caoutchouc form an open tube of double length and so on.

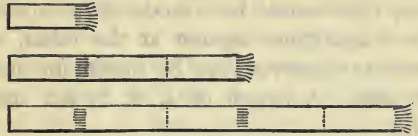
It is clear that if we denote a region of maximum motion by a bundle of horizontal lines, and node by a vertical dotted line, we have in a tube open at one end the following condition (fig. 65) when the tube is sounding its fundamental note. If we attach another unit length to the tube, it refuses to sound, because to do so would necessitate a region of maximum motion at the bottom, an

Fig. 65.



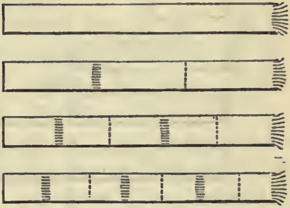
evident impossibility. But a tube of 3 units length will sound, and so will all odd multiples of the unit (fig. 66) tube. Further, if we examine what different forks will resound to the same tube close at one end, we find that

FIG. 66.



a fork giving rise to three times the number of vibrations, one giving rise to 5 times, 7 times, and so on, will resound (fig. 67), while no even number multiple of the vibrations (submultiples of wave lengths) will do so, for they necessitate maximum motion at the bottom. The first overtone, sometimes called 'harmonic,' got by blowing with violence across the open end of a tube closed at the bottom, has therefore $\frac{1}{3}$ wave length of the fundamental, the second $\frac{1}{5}$, and so on.

FIG. 67.



Take now a second tube of the same length as the first, also closed at the bottom, and fasten the closed ends together. The second tube will take up the vibrations of the same fork. The double diaphragm in the middle may be withdrawn, for the pressure on it from one side is always equal to that on the other; so that a tube open at both ends must be twice as long as a

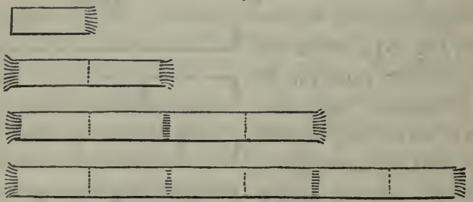
FIG. 68.

tube closed at one end to sound the same note. In the former case an automatic node is formed in the middle. Three unit lengths of tube refuse to sound to the same fork, because the wave length being the same, there would be a node at an open end if there were maximum motion at the other, whereas there must obviously always be maximum motion at an open end. A length of 4, 6, 8, &c. units will resound,

FIG. 69.

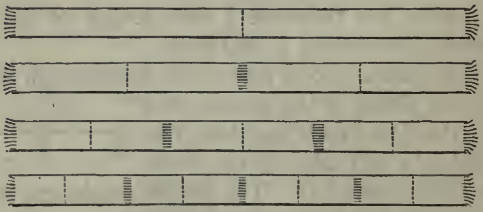
Or, if (fig. 70) we take the first open tube which re-

FIG. 70.



sounds to the fork as the unit length, all open tubes which

FIG. 71.



are multiples of this length will resound. And in the same manner as before, on examining what forks resound

to the same open tube (fig. 71), we find that they are all the forks whose vibrating numbers are multiples (or wave's-length submultiples) of the lowest. This series includes, therefore, all the octaves of the lowest fork.

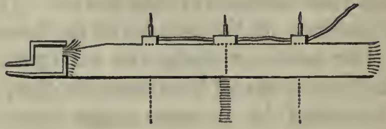
§ 98. The node or nodes in an open tube, and the regions of maximum motion, can be examined in an open organ pipe. Such a pipe has one free open end, but the end where the air current vibrates is not so free. A little tambour, covered loosely with tissue paper, will rustle at the top and bottom of the tube, but remain tranquil near the middle.

FIG. 72.

A node being a place where the change of density is greatest, and half-way between the nodes being where there is least change of density though greatest motion, the existence of one or other condition can be shown by the effect on flames as follows. Let an open organ pipe (fig. 73) have three holes cut along one side, at $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$ the pipe's length from the end. These holes are covered with gold-beater's skin, and the skin is covered by a little box in each instance. Into all three of these side chambers coal gas is led, and to each there is a small jet at which the gas can be burnt. The jets are set burning at all three places. When the fundamental note is sounded the central jet alone is extinguished. For the alternate compression and rarefaction of the air at the node which is formed there moves the membrane in and out, and so puts out the flame. On sounding the next harmonic, that is, the higher

octave, nodes are formed at the first and third gas

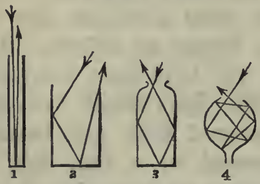
FIG. 73.



jets, and these are extinguished while the central one now continues burning. It is evident that the first experiment only shows a differential effect, since the positions of the jets are not the regions of greatest motion, and therefore are not free from variation in pressure.

§ 99. **Resonance.**—The acceptance by a tube of a system of waves of a sonorous body is called resonance; and for narrow tubes the relationship established in §§ 97, 98, holds good. But with wider tubes, even when cylindrical, but more markedly if of irregular shape, the relationship between the sound wave and the vessel measurements is not so obvious.

FIG. 74.



Thus a wider cylinder will present a possibly longer path by dint of reflexion, so that such a tube will also sound to a graver fork, and, indeed, may sound more fully to a graver fork, for, by repeated reflexion, it can furnish a great variety of paths of the required greater length.

Let us next employ the resonant cavity to measure

the relative rates at which sound travels in different gases, and so confirm the formula

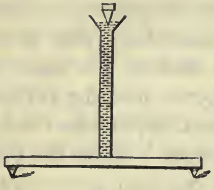
$$v \propto \sqrt{\frac{e}{d}}$$

Fill a tube so far with water that it resounds to a given fork. Lead a current of carbonic acid gently to the surface of the water, so that the air may be expelled by displacement. The tube of carbonic acid no longer resounds to the fork, but it does so if water be poured in so as to shorten the resonant column. This shows that for sound to reach from end to end (and back again) in the same time in two columns, one of air and the other of carbonic acid, the carbonic acid column must be the shortest, or, in other words, the sound travels fastest through air. If, on the other hand, a tube be taken closed at one end, inverted, and filled by displacement by hydrogen or coal gas, a fork which resounds to this tube will do so, if the gas is replaced by air, only when the column is shortened. A copper tube which resounds to a fork when heated, does not do so when cooled, unless virtually shortened. All these experiments show that sound travels more slowly through a gas of greater density, if the elasticity remains unchanged, as is the case in all these experiments, since the gas has the same elasticity as the air. When a gas is compressed its density and elasticity increase together, and accordingly no change in velocity occurs. This is the condition of change brought about by variation in barometric pressure; such a variation accordingly is not accompanied by any change in sound velocity. The acquirement, however,

of aqueous vapour, which diminishes density without affecting elasticity, increases velocity.

§ 100. **Longitudinal vibrations of liquids and solids.**—Although the transverse vibrations of solids are accompanied and caused by states of compression or rarefaction, or both, these states do not pursue the same course as the vibration itself does. Both solids and liquids are, however, capable of such compression and rarefaction, and so of conveying sound waves in the same sense that air does. This is shown in the case of liquids, by fastening a tube containing water, mercury, or other liquid, fig. 75, on to a sounding-board, and plunging into the top of the liquid a cork cone fastened to the end of a tuning-fork. The sound heard proves that the wave of condensation travels through the water. The actual velocity of sound through water is about four times that through air. The actual comparison between the rate of a wave through air and through a solid is established as follows: a tuning-fork is held over a narrow cylinder into which water is poured until the maximum resonance is reached. A solid cylindrical rod, say of oak, is held in the middle between finger and thumb, and one of the free ends is rubbed longitudinally towards the middle with a piece of leather covered with powdered resin; a pretty clear note is thus produced, the origin of which is the breaking of the brittle resin powder at a certain

FIG. 75.

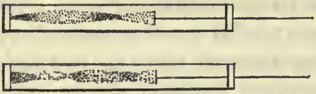


degree of strain, setting up of a wave of altered density, which, after being reflected at the further end, returns to the end being rubbed. It then beats and pulls the air, giving rise to an audible air wave; the time required for the next solid wave to pass down and up: that is, the time interval between two solid waves (and therefore between the two air waves to which they give rise), is directly proportional to the length of path (twice length of rod) and inversely proportional to rate of travelling. If the rod be so cut down that it gives the same note as the tuning-fork and its resonant column, it follows that the solid wave takes the same time to travel from end to end of the rod as the air wave takes to travel from the mouth of the jar to the water surface and back again; for it must be borne in mind that a rod vibrating as above described resembles a pipe open at both ends, which (§ 97) has been shown to have twice the length of the closed pipe giving the same note. Thus it is found that if the air column resounding to a given fork be 6 in. long, an oaken rod must be cut down to about 10 feet to give the same note. The velocity of the oaken wave is to the velocity of the air wave as 10 feet is to twice 6 in., or as 10 to 1. A deal or steel rod must be 32 times as long, or, reckoned from the middle, 16 times as long as the similarly vibrating air column.

§ 101. The comparative rate of metal waves is found in a similar way, but wires may be employed. The actual wave lengths can be traced out by the arrangement of lycopodium, if the waves be reflected from the bottom of a tube, so that nodes may be established. And this method enables us

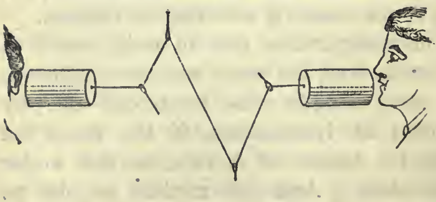
either to compare different solids, using the same gas in the tubes, or different gases, using the same solid exciter. In fig. 76, suppose there are two rods of the same length, one of brass and the other of glass, each supported in its middle by a cork fitting into the end of a glass tube, the other end of which is closed. If the tube be of the right length, measured from the end of the rod to the bottom, that is, any multiple of the half wave length of the note, stationary waves will be formed, in whose nodes the lycopodium accumulates. If both rods are of glass, and one tube be filled with hydrogen, the waves in the latter are found to be longer than those of the air.

FIG. 76.



§ 102. The conveyance of sound through solids is not only quicker, but more perfect, than through air. A watch is heard to tick when placed at the end of a deal rod several yards long, if the ear be placed at the other end. A piano in one room gives its vibration to wooden rods passing into a room several score yards off, and will, if the rod be connected with a sounding-board in the second room, appear to be played there. If two round tubes, about 3 in. in diameter, have a membrane stretched tightly over one end of each, and a thread be fastened to the

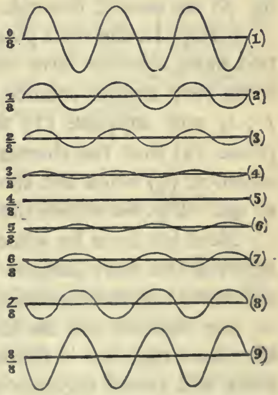
FIG. 77.



membranes through the centre by means of knots and a little wax, the voice speaking into one can be heard in the other, though the thread be 20 or 30 yards long, provided it is kept moderately stretched. It may even be carried round corners, if it be supported at the corners by short flexible threads. By employing steel wire and metal membranes, conversation can be heard from a quarter of a mile.

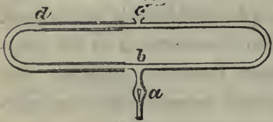
§ 103. **Interference. Beats.**—If a mass of air is acted on simultaneously by two systems of waves, it will be affected (1) according to the relative phases of the two systems, if they are of equal length, and (2) according to their lengths. We need only look at a few cases of each. Let us suppose that in all cases the waves have equal amplitudes. First, let the wave systems be of equal wave length, and start together. Fig. 78, (1) the waves augment one another's amplitude throughout. If the one system is $\frac{1}{8}$ of a wave length before the other, we get (2), and so on. A difference of $\frac{1}{2}$ wave length gives perfect extinction. If the difference be still further increased, the joint wave system increases in amplitude, and therefore in loudness, until $\frac{8}{8}$ (9) is reached, which is the same as (1). To show this, a tube, shown in fig. 79, is used. A caout-

FIG. 78.



chouc tube containing a whistle is fastened to *a*. The sound waves are divided at *b*, half each wave, that is, condensation of half amplitude, and rarefaction of half amplitude, goes to the right, and half to the left. If their paths be equal, they meet again as they parted, and augment one another's amplitude, and so restore the full sound. But if the movable loop, *d*, be drawn out, so that the additional path of the left limb of the wave is equal to half the wave length, the two wave systems will encounter one another at *c*, in opposite phases, as in case (5), fig. 78, and the two wave systems produce silence. The gradual extinction of the sound, and its gradual restoration, as the sliding piece is pulled twice as far out, shows that all the cases of fig. 78 are passed through.

Fig. 79.

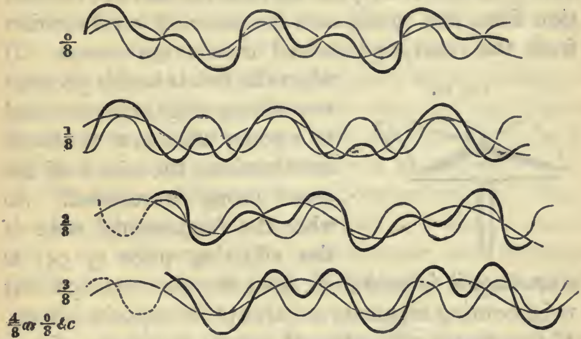


§ 104. In the next place, consider the effect which two wave systems have on one another, if they have some very simple relation in their wave-lengths, say 1 : 2, and suppose (1) that they start in the same phase, (2) that the shorter wave is $\frac{1}{8}$ a long wave in advance, (3) when the short one is $\frac{2}{8}$ in advance, and so on. Fig. 80 shows the effect.

Next let there be some other but integral relation between the wave-lengths of two wave systems which are started simultaneously, fig. 81, where seven waves of one system are as long as 6 of the other. If they start together it follows that the first condensations will travel together and the amplitude will be their sum. Condensation No. 3 of the 6 system will

be sent off at the time half-way between the 3 and the 4 of the 7 system, that is, at the time when a maximum

Fig. 80.



$\frac{4}{8}$ as $\frac{0}{8}$; $\frac{5}{8}$ as $\frac{1}{8}$; $\frac{6}{8}$ as $\frac{2}{8}$; $\frac{7}{8}$ as $\frac{3}{8}$; $\frac{8}{8}$ as $\frac{0}{8}$.

rarefaction of that system is evolved. These will annihilate one another. When the 6th of the 6 system is sent off, the 7th of the 7 system will be sent off also, and these will assist one another.

Fig. 81.

A burst of sound called a *beat* is heard when the region of augmentation reaches the ear; these are alternated with periods of comparative silence.

§ 105. Interference is shown experimentally by the tuning-fork. If such a sounding fork be held over its resonance tube horizontally and gradually revolved,

four positions are found in which the sound is almost extinguished, and these positions are when the side faces of the fork are at about 45° with the resonance tube. In the corresponding lines the wave of rarefaction from one prong cuts the wave of condensation from the other, and mutual destruction ensues. If when the fork is in this position one of the prongs be surrounded by a paper tube, so as to absorb its vibrations, the sound of the other prong is restored. So when the fundamental note of the vibrating plate (§ 95) is sounding, it is weakened from the circumstance that neighbouring segments are always in opposite phases. If two pieces of cardboard cut to the shape of two segments be held over two opposite segments, so as to kill their sound, the other two segments sound louder. On setting the plate in any other condition of vibration and passing the palm of the hand close over its surface without touching, its effect in lessening the interference is made audible.

Fig. 82.

It follows from § 104 that the beats, being conditions of density, travel through the air at the same rate as the waves whose interference causes them. The more nearly notes are in unison, the longer the interval in time and space between the beats. Practically, the audibility of beats is of great importance in estimating the difference between notes in near accord; and the elimination of beats is a guide in bringing notes to strict accord. For the number of beats which two notes sounding together give in a second is the diffe-

rence between the numbers of their individual vibrations in a second. Thus in § 89, where the bridge of the monocord was moved till unison was obtained, perfect unison is preceded by beats which get less and less frequent till they cease to be distinguishable. On continuing to move the bridge in the same direction they become audible again, and as the bridge is moved the rapidity is increased—they get too numerous to count, until, when they reach about 32 in a second, their existence is perceived as discord.

Beats are readily produced between forks in unison by loading one prong of one with a piece of metal stuck on with wax. The beats become more frequent as the metal is fixed nearer to the end, and also as its weight is increased.

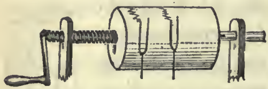
§ 106. Small flames burning inside open tubes often, by establishing currents, blow themselves partially out, so that full combustion ceases; the current stops and the flame strikes back; this gives rise to an air wave, according to the length of the tube, in such a way that the advent of the air wave at the flame causes a flicker of the flame, and the flicker of the flame causes an air wave. Two such tubes, if alike, will sing in unison, but by sliding up a paper tube surrounding one, its tube is lengthened, a lower note results and beats are heard. That such a singing flame palpitates is seen by moving the head quickly from side to side while looking at it or by focussing it by a convex mirror upon a screen and turning the mirror quickly but slightly on a vertical axis. The image appears then in different places when of dif-

FIG. 83.

ferent sizes, so that a uniformly jagged appearance results.

§ 107. **Sinuosities.**—The above method of making palpitation visible is only one instance of the device by which a to-and-fro motion is converted into a wavy or sinuous one by combining it with motion of translation. If a piece of elastic wire is fastened to a prong of a tuning-fork and held in such a way that when the fork sounds the wire scratches lampblack off a sheet of glass, the scratch will be a line. But if either the fork is drawn along or the glass shifted, a sinuous line is laid bare. If the relative movement endures for a second, whether that movement be fast or slow, there will be as many crests on one side of the sinuosity as there were complete vibrations. Use has been made of this method for regulating forks to agree with a normal fork. Both forks are provided with little styles of bristles.

FIG. 84.



These delay the vibration a little, but affect both forks alike. The styles rest upon a cylinder which is covered with lampblack and can be turned on a horizontal axis which is a screw. In this way the cylinder advances as it turns, and the sinuosities take a spiral form. The number of waves between two lines parallel to the axis is counted, and the fork under trial filed accordingly (see § 85).

§ 108. **Effect of motion of the source of sound.**—If we were to begin to move away from a source of sound the moment it began to give forth n vibrations per second, and were to move at the rate of 1,100 feet

a second, it is clear that the sound would never overtake us. If we were to move at the rate of 550 feet a second, at the end of the second we should have been overtaken by $\frac{n}{2}$ sound waves, because the $\frac{n}{2}$th sound wave would be at 550 from the source. Hearing $\frac{n}{2}$ sound waves in a second, we should hear the octave lower than we should have done had we remained at rest. And inversely, if we started at a distance of 1,100 feet from the source of sound, and began moving towards the source of sound at the rate of 1,100 feet a second the moment the source of sound began giving off n vibrations, we should hear nothing in the first half-second, or 550 feet. Then we should hear the whole n vibrations in the next half-second, or 550 feet, and reach the sounding body just as it had completed its nth vibration. Evidently, therefore, the pitch of the note which we should hear would be an octave higher than it would have been if we had remained at rest. It is also clear that this change of pitch by motion is the same whether we move or whether the source of sound does so. This is shown by fastening a whistle to the end of a long caoutchouc tube, and whirling the tube round while the whistle is sounding. To a person standing at some distance the pitch of the note is heard to become graver as the whistle recedes, and shriller as it advances towards him.

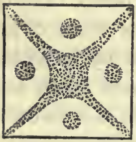
Sympathy. — If two solid bodies, such as two strings or tuning-forks, are capable of giving out the same note when sounded, the sounding of one alone will cause the other to sound if the two be in con-

nection by any elastic medium. Thus if two tuning-forks placed side by side, facing one another, be related as a note and its octave, and a third fork in unison with one of them be sounded and placed between them at the same distance from each, the unison fork alone will sound. A pellet of wax hung resting against this one will be thrown off, while a similar pellet attached to the other will remain at rest. This may be regarded as an absorption of vibration.

These experiments are interesting on account of their supposed relationship to similar absorption of light rays, but are here chiefly noteworthy inasmuch as they confirm the assertion that there is little change in the wave length in its passage through the air.

§ 109. **Approach caused by vibration.**—The air in the neighbourhood of a vibrating body is on the whole somewhat less dense than when the body is at rest. If a mixture of lycopodium and sand be scattered on a vibrating plate (§ 95) which has broken up into segments (fig. 85), while the sand collects on those lines where there is least motion, the lycopodium collects in the complementary regions where the motion is greatest. On examining those little heaps of powder the particles are seen to enter the heaps at the base, rise in the middle, and roll down the slope, showing that there is an inrush of air laterally to supply partial rarefaction. Further, if one limb of a large tuning-fork be fastened air-tight in a tube (fig. 86), from which a capillary tube leads into water, when the other limb is bowed the water sinks in the

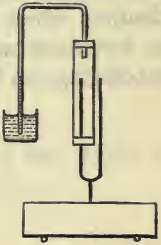
Fig. 85.



capillary as though a vibrating fork occupied more room than one at rest.

Finally, a series of air waves from a fork on striking on a lightly suspended surface, either smooth or rough, cause the surface to approach the fork; or if the surface be fixed and the fork movable, the fork approaches the surface. This is the case whether the surface be smooth or rough. A toy caoutchouc ball floating on clean water shows this effect to perfection.

FIG. 86.



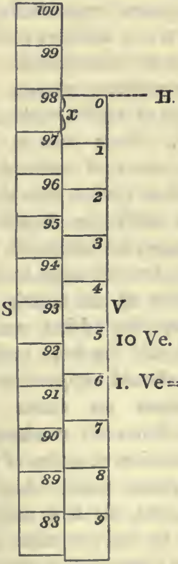
§ 110. **The Phonograph.**—By speaking on to a stretched membrane, the other side of which carries a style, and moving a smoked glass surface at a uniform rate across the style, a permanent record is obtained of the vibrations corresponding to the words uttered. The logograph is a device of this kind. In the phonograph not only is a similar record preserved, but it is of such a nature as to be usable in the reproduction of the sounds and articulate words. A spiral groove is cut in a revolving drum (§ 107, fig. 84), which turns on a screw axis of the same pitch as the groove. Tinfoil is smoothly rolled upon this, so that there is a spiral worm cavity. A little drum, whose sides are of wood and whose membrane is thin sheet iron, has a style fixed to its centre outwards, and this can be brought and fixed so that the style just touches the foil. On turning the cylinder round and speaking into the drum, the style makes a series of indentations

on the foil. On passing this series of indentations beneath the style of the same drum, or better, beneath that of a drum made of paper, the style enters the cavities which the first one made, and sets its drum in vibration, which thus reproduces the sounds which the first drum received. The complex vibrations of part-singing can be registered and reproduced.

APPENDIX.

§ 111. **The Vernier.** -The use of this device for getting exact measures of distances, heights, and angles, depends upon the fact that it is easier to perceive exact coincidence in position than to estimate exactly a difference of position. A vernier is a small scale sliding edge to edge with the main scale, and having its divisions a little further apart than those of the main scale. If the object is to read to tenths of the divisions of the main scale, the length of the vernier is eleven of the divisions of the main scale, and this length is divided into ten equal parts. Each division of the vernier is $1\frac{1}{10}$ as long as a division of the main scale. If the main scale is numbered from below upwards, the vernier is numbered from above downwards, its top being marked

FIG. 87.



10 Ve. = 11 Sc.

1. Ve = 1. Sc. + $\frac{1}{10}$ Sc.

o. Thus let it be required to determine the height of the line H, fig. 87, which falls between the 97th and 98th divisions on the scale S. Push up the vernier V till its top or zero line coincides with H. Look down the two scales and you see that 89 very nearly coincides with 8; assume that it does so. The height of H is $97 + x$ scale divisions, and x is of such a length that $x + 8$ scale divisions are equal to 8 vernier divisions, or to $8 + \frac{8}{10}$ scale divisions; that is, $x + 8 = 8 + \frac{8}{10}$, whence x is $\frac{8}{10}$ of a scale division and the height of H is $97 + \frac{8}{10}$.

The divisions on the vernier of a sextant are generally $\frac{21}{20}$ of the divisions on the main scale; the latter are arcs representing 20 minutes or $\frac{1}{3}$ of a degree: the vernier enables reading to be taken of $\frac{1}{20}$ of $\frac{1}{3}$ of a degree, or to one minute.

§ 112. **Parchment paper.**—Mix slowly two pints of commercial oil of vitriol with one pint of water and cool to about 15°. Pour into a shallow basin, and drag through it a sheet of unsized paper (Swedish filtering paper is good) at such a rate that each part of the paper is in contact with the liquid for about five seconds; plunge the paper immediately into a pail of water and thence after a few minutes into a basin under the tap. After a quarter of an hour's rinsing a drop or two of ammonia may be added and the rinsing continued. The paper should be kept moist. A strip of this paper an inch wide should support at least twenty pounds.

§ 113. **Hints on glass working.**—Perhaps the following few hints on working in glass may be useful for the construction of some of the apparatus described.

To cut a glass tube.—Lay the tube over the edge of the table, and tilt it a very little, so that the place where it has to be cut rests on the edge of the table. Hold the tube close to this place, and give one long and steady cut with a three-cornered file, guiding the file with

the thumb-nail. If the tube is very thick in the glass as well as in diameter, repeat two or three times in the same place, but don't saw. Hold it horizontally on both sides before the chest, with the cut towards you ; pull, and bend as little as possible. The less the bending the cleaner the cut.

To smooth the ends of tubes.—Tubes which have to be passed through corks, or connected by caoutchouc tubing, should have their ends smoothed. Warm the end by passing it through the air-gas burner, then hold it obliquely in the flame, turning it till the edges are rounded : this is seen to happen soon after the flame begins to be coloured yellow by the sodium of the glass.

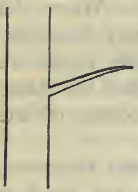
To bend tubes.—Tubes, unless of great thickness, should be bent with one motion, unless the bend is required to be a gradual curve. The two parts on either side of where the bend is to be are held as near as possible to the centres of gravities, lightly with the same grip as a pen is held, under-handed, thumb upwards. The region being gradually warmed, the tube is held rather obliquely through the solid part of the flame, being constantly turned round. As soon as the flame burns yellow and two or three inches of the tube are found to be soft, the tube is removed from the flame and bent to the required angle. A tube which has been bent so sharply that there is a crease in the bend is pretty sure to break there.

To close the end of a tube.—Tubes not more than half-inch in diameter may be closed over the simple air-gas burner. They should be softened near the end and the end pulled off : this leaves a tail of glass : the root of the tail is heated and again pulled off, and so on till the tail is very slender ; then cut it off and heat the stump in the flame : it will melt and run up, making the end

about of the same thickness as the rest of the tube. When the end is red-hot it may be further smoothened by removing it from the flame and gently blowing into the open end. To close a wide thick tube, the table blow-pipe is preferable.

To fuse platinum into a glass tube.—The whole region being heated, a fine blow-pipe flame is made to play on the point, and when this is soft a platinum wire is stuck to it and rapidly pulled away; this draws out a little tube: this tube is cut off as close as possible to the main tube, and the end is heated till its edge shrinks so as scarcely to project upon the main tube. The platinum wire is thrust through the hole, which it should nearly fit; the glass is softened, and the red-hot wire is worked a little in the hole, both in and out and round about, to enforce complete contact.

FIG. 88.



To join tube to tube, end to end.—If they are of the same or nearly the same diameter, the ends should be cut clean and flat, but not ground; the further end of one tube should be closed with a cork. The ends being thoroughly and uniformly softened, are pressed gently together; for steadiness the wrists may be in contact. The joint is allowed to get sufficiently cool to prevent bending when the whole is held in one hand. A pointed flame of the blow-pipe so made that the tube is not softened all round is applied in succession to three or four points of the join, and air is gently blown in at the open end, not so as to make a bulb but so as to restore the cylindrical form. By this means the appearance of a joint is quite erased beyond a little irregularity.

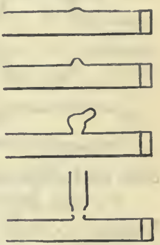
If the tubes are of very different diameter the wider one should be drawn out with much heat and little pulling, and constant rotation, so that the glass of the

neck may be of a reasonable thickness. The neck being cut through, proceed as before.

To join a capillary tube to another, a bulb should be blown on one end of the capillary tube and then broken and the edge chipped off pretty even. The edge of the so formed tube is allowed to collapse till it is of about the same width as the tube to be joined, they are joined as before.

To join tubes end to side.—One end of each tube being permanently or temporarily closed, a pointed flame is directed upon one side of the tube whose side has to be pierced, and by blowing a gentle elevation is produced: this is increased by two or three subsequent blowings until by a strong puff of breath the side is blown through. The remains of the thin glass bulb are removed by pressure, and the edge of the hole rounded in the flame; the edge of the other tube is then applied and fused on as above.

FIG. 89.

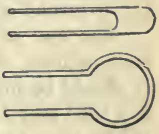


A simple constriction in a tube is made by using a large blow-pipe flame and turning the tube round and round without drawing it out.

FIG. 90.

A bulb is blown on the end of a tube by first closing the end and letting it fall together till a good mass of glass is collected at the end which must be very uniformly hot when the breath is gently forced in at the open end.

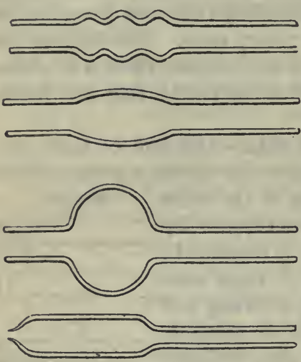
FIG. 91.



To blow a bulb on the middle of a tube, one end of the tube is closed and the place required is uniformly heated and the ends are gently pushed together while air is blown in at the open end.

If it be required to blow a large bulb of thickish glass on a narrow tube, the narrow tube should be joined to a piece of wider tube and the bulb blown on the latter.

Fig. 92.



To cut sheets of glass with a diamond.—The glass should be placed on a piece of cloth and the cut made with a single stroke towards you, taking care to cut quite up to the edge next you. The plate is held in both hands with the thumbs above the glass quite on the edge, one on each side and quite close to the cut. It is then bent upwards.

To cut a round piece of glass, such as a flask or beaker, a crack must be made in the vessel by heating a part of it and dropping a drop of water on the heated part. A piece of pointed charcoal or pastile is set on fire and the point moved a little in advance of the crack, which follows it, and may be directed along any dry ink line previously made on the glass. The sharp edge, if it be irregular, as it is apt to be, is chipped regular by a key, between the wards of which the edge is placed; the fit should be good and only the edge placed in; the key is turned outwards.

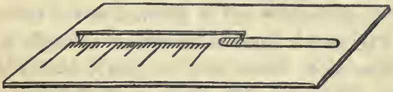
The end of a tube may be ground off flat by being held against the flat side of a grindstone, using water. It should be finished on a flat sandstone slab. The end of a tube may be at once ground flat on the slab; the top of the tube being lightly held serves as a pivot: a small circular motion is given to the lower end.

To bore a hole in glass, an old file is ground to a

three-cornered borer, finished on the hone and hardened by heating it red-hot and quenching it. The file is placed in a handle and worked with the hand or inserted in a watchmaker's drill. The point to be bored through is kept moistened with oil of turpentine, and the glass is fixed immediately beneath it. When the hole is half-way through, the plate is inverted and the hole met on the other side.

§ 114. **To etch a scale on glass.**—Steel millimeter scales are sold, and from these millimeter divisions are easily transferred to glass. The glass is cleaned and heated and covered uniformly, and not too thickly, with melted beeswax and turpentine, 20 of wax to 1 of turpentine; the scale and the glass are stuck with a little

FIG. 93.

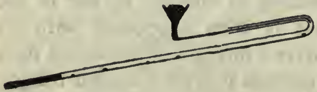


soft wax on a table, as in fig. 93. A rod about 2 feet long has two stiff needles driven through its ends, and while one needle is placed in a division of the scale the other scratches the wax off the glass; and, to prevent the scratched lines being too long, two straight-edges may be fastened along the glass. Figures having been added with a needle-point, the glass is painted over with a solution of hydrofluoric acid. In about half a minute the acid is washed off and the wax removed by spirits of wine or turpentine. A clearer etching is effected by use of the gaseous acid. The glass is then supported with its marked side downwards over a mixture of powdered fluor spar and oil of vitriol contained in a long leaden trough, which is kept for some hours in a warm place. The liquid acid, and especially the gaseous acid, is excessively

poisonous, and the etching should be performed where there is thorough ventilation.

§ 115. **The siphon barometer.**—To make a siphon barometer, a piece of well annealed soft-German or lead glass, about 42 inches long, $\frac{1}{2}$ an inch thick outside and $\frac{1}{4}$ inch inside, and of the same bore at both ends, is thoroughly cleaned and dried. The final drying is effected by passing it to and fro through an air-gas flame throughout its whole length, and then heating nearly to softening a spot about 4 inches from one end. Air is drawn through from the other end. The place which was heated strongest is now softened in the blow-pipe flame, and the short end, say 3 inches, is drawn off as quickly as possible. A sharp flame is now applied to the root of the tail, the tube being continually turned and a fresh piece drawn off, and so on. Finally, the short and slender tail is allowed to fall back upon the glass. The end is then to be rather strongly heated in a larger blow-pipe flame and air gently blown in from the other end. This must be done until the inner surface of the closed end is quite smooth and dome-shaped. The whole of the tube is again to be strongly heated, and, a narrow tube being passed down to the bottom, air is to be drawn through the latter. The narrow tube being withdrawn, the barometer tube is bent in a smooth bend, commencing at about 34 inches from the closed end. The bend is so made that the shorter and open end is as close as possible to the longer limb and parallel to it. The tube is now supported on its back, inclined downwards towards its closed end and its open limb upwards. A little funnel has its tube end drawn out and slightly bent down at its

FIG. 94.



extremity; the drawn-out end is inserted into the open limb of the barometer till its extremity is above the bend in the latter, the tube of the funnel having been previously so bent that when it is so inserted the funnel stands upright. The funnel with its tube, as well as the barometer, are all dry and warm. Perfectly pure mercury is heated to about 100° C. in a basin and poured into the funnel, which must be kept well filled. The drops of mercury roll down the barometer tube and completely displace the air. As soon as the barometer tube is filled to the bend, the funnel tube is removed and the whole brought gently to the vertical position. Should any minute air-bubbles appear, which is never the case if the above directions are strictly adhered to, the barometer is gently turned completely over, so as not to spill mercury, and the closed end is tapped vertically upon with a block of wood. The air-bubbles rise to the free surface. Suppose all the bubbles to be got rid of, the barometer is turned upright and a little more mercury is added to the open end. If the vacuum is perfect, when the barometer is gently inclined the mercury rises to the top with a sharp click.

ELEMENTARY EXPERIMENTS

RELATING TO

SOUND AND WAVES.

N.B.—*The numbers in brackets in this list refer to the paragraphs of the list of Apparatus and Materials, pp.* 151–154.

WAVES.

1. **Transmission and Reflection of Transverse Motion in Elastic Cords.**—An empty vulcanized caoutchouc tube 12 feet long is fastened to the ceiling at one end, and is held at the other in the hand in a nearly vertical position. Strike it with the other hand. A half wave travels along, and comes back reversed (1).

2. Two similar tubes, equally stretched, are similarly and simultaneously struck; rate of motion of displacement is the same (1).

3. Stretch one tube more than the other, keeping each at its full length. Compare time of wave from end to end. Compare rate of wave by making the unequally stretched tubes of equal length (1).

4. Fasten an empty tube and a sand-filled tube side by side. Stretch equally and take equal lengths. Compare rates of wave motion. Stretch sand-filled tube till the rates are equal, taking equal lengths (1).

5. Fasten an empty and the sand-filled tube end to end and fasten the end of one to the wall. Send a half wave up the other. Notice change of rate and change

of amplitude when the half wave passes from one to the other ; also after reflection (1).

6. Make the half wave with either of the tubes longer and longer by shaking the end more slowly until the front of the reflected half wave meets the front of the next advancing half wave in the middle of the tube. Formation of node in the middle. Wave length equal to length of tube. Formation of one complete stationary wave. With half rate of excitement the tube swings as a whole, and the wave length is double the length of the tube. By quicker motion break up the tube into segments separated by nodes. Repeat with differently stretched and loaded tube (1).

7. **Transmission and Reflection of Transverse Motion in Liquids. Water-Waves.**—Examine motion of water in trough (2). Fill trough nearly full of water, place chips of cork along edge of water, depress and elevate block (2) at one end of trough and watch the motion of the floating cork chips. Substitute little beeswax balls mixed with iron filings till they just float and place them at various depths. Observe the closed curves in which the balls move.

8. Take the two circular zinc troughs (3). Nearly fill with water. Set the water swinging (oscillating) in various ways in both troughs (*a*) by tilting them, producing a nodal line in the middle (*b*) by moving up and down in the centre some light circular body, such as an empty beaker (3). Show, by counting with a watch, that the number of times the water returns to a given position in a given time is greater in the smaller trough, and that the two numbers are inversely as the square roots of the troughs' radii or diameters. Show, by hanging a bullet from a thread (3) having the length of the trough's radius, that the motion of the water in case (*b*) is, with both troughs, at the same rate as the pendulum. Examine the motion

of the water in case (*b*), and show that a nodal ring is formed nearly at one-third of the radius from the circumference, and that the vertical motion at the centre is nearly double that at the circumference. As the wave's path is from the centre to the circumference and back, show that the rate of wave progression is directly proportional to the square root of the wave length.

9. **Air Motion in Mass. Vortex Rings.**—Fill case (4) with smoke or chloride of ammonium in suspension. Hit the canvas at the back, and examine the motion general and internal of the vortex rings. Blow out a candle 20 feet off. Send one ring to overtake another, and notice rigidity.

10. **Partial Vacuum on Dispersion.**—Balance the piece of pasteboard (6) on the point of the finger ; place the disc with the tube over it, and blow through the tube. Notice that the discs adhere together, showing that, by the dispersion of the air column in the tube when it meets the lower disc and passes between the two, the air is rarefied.

11. **Approach caused by Vibration.**—Float a toy air ball (7) on clear water, and show that when a tuning-fork which has been struck is brought near it, the ball approaches the fork.

12. **Connection between the Volume and Density and the Pressure on or Tension of a Gas.**—Mercury is poured into the open end of the tube (8) just in sufficient quantity to cover the bottom of the bend. The air in the shorter limb is then exactly at the atmospheric pressure. Any quantity of mercury is then poured in, and the difference in height between the two columns is measured. The pressure to which the gas is now subjected is the atmospheric pressure (for which the barometer is consulted) plus the pressure of the difference of the mercnrial columns. The volume of the air, which may be considered as the length of the air column in the

shorter limb, is found to be in all cases inversely proportional to the pressure.

13. **Heat liberated on the Compression and absorbed on the Expansion of Air.**—Fasten German tinder to the bottom of the wooden rod in (9) and, placing the closed end of the tube on the table, thrust the wooden rod down. After one or two thrusts the tinder will light. Put a drop of bisulphide of carbon on a pellet of cotton wool and roll it in and out of the tube, then thrust the rod down, the bisulphide will flash. Clean the tube and place in it a pellet of cotton wool moistened with water; push the rod down to about a quarter the length of the tube from the bottom. After a time pull it up suddenly. Clouds of condensed watery vapour will be formed.

14. **Propagation of Compression and Rarefaction through Solids and Liquids.**—Arrange "solitaire" balls or marbles (10) in a groove, and hit the row with one, two, or three, noticing the number which are sent off from the other end.

15. Strike tuning fork (7) and hold its root on one end of a deal rod (7), and place a board (7) on and off the other end. This shows that the waves of compression and rarefaction travel along the rod.

16. Fasten one end of the sand-filled tube (1) to the ceiling. Fasten a piece of paper near the top. Send a wave of rarefaction up the tube by quickly pulling the free end.

17. Fill tube (12) with water. Strike fork armed with cork cone (12), and plunge cone into water at top of tube. The sound heard shows that the wave of compression travels through the water.

SOUND WAVES.

18. **Propagation and Reflexion of States of Compression and Rarefaction through Air.**—The tubes (13) are fitted end to end. A watch is placed at such a distance from the ear as to be inaudible. The tube is placed over the ear and directed towards the watch. The ticking becomes audible.

19. The tubes (13) are supported horizontally at an angle of 90° with one another. A watch is placed at the end of one, and the ear at the end of the other (the ends furthest apart), and screens are placed between the ear and the watch till the latter becomes inaudible. A piece of cardboard or the hand or a flat flame is placed at their contiguous ends, making 45° with each tube. This makes the watch audible, and proves the law of reflexion.

20. **Destruction of Sound Waves.**—The tubes (13) are arranged horizontally end to end with an interval of half an inch between. The watch is placed at one end of one tube, the ear at the other end of the other tube, at such distances that the watch is faintly audible. A dry cloth placed between the tubes does not destroy the sound, a wet one does; so does a current of heated air from a flame.

21. A watch is loosely wrapped in folds of flannel till it is inaudible. A deal rod with board attached (14) is thrust amongst the flannel till it touches the watch, which then becomes audible.

22. A hand bell is heated over an air gas burner. At a certain temperature it ceases to ring when struck.

23. A glass funnel (16) is stopped at its neck and partly filled with a solution of carbonate of sodium. When struck it rings. Add a solution of tartaric acid; the effervescence causes a dulness in the sound.

24. **Refraction of Sound.**—A toy air-ball (7) is filled with carbonic acid. This is made by putting some marble into the flask (17), putting in the cork, and then pouring water and hydrochloric acid down the straight tube. The air-ball is emptied of air and tied over the end of the bent tube. When filled it is tied off, and hung between the watch and the ear. The watch being two or three feet off and the ball close to the ear, the loudness of the watch's ticking is increased.

25. **Formation of Notes.**—The humming-top (18) is spun on a hard surface. A card is held against the toothed wheel. A note is produced, which becomes lower in pitch as the top moves slower. Air is blown through the tube (18) on to the outer and on to the inner ring of holes. The note produced by the former is always an octave higher than that by the latter.

26. **Transverse Vibrations of Rods.**—Verify the generalisation that if the length of a rod fastened at one end is l, and its thickness, in the plane of vibration, is d, all other things being the same, the number n of vibrations per second (or in a given time) is such that

$$n \sim \frac{1}{l^2} \text{ and } n \sim d$$

or

$$n \sim \frac{d}{l^2}$$

Clamp deal rod (18) flatways (narrow face up) horizontally in the vice (18) between two pieces of wood, so that 10 feet are free; set it vibrating horizontally. Adjust a pendulum bullet (3) so as to oscillate with the rod. Adjust another bullet so as to oscillate twice as fast as the first. It will be found that the second pendulum will keep time with the rod (*a*) if the rod is 10 feet long and turned edgeways, (*b*) if it is made seven feet long and vibrates flatways ($10^2 = 2 \times 7^2$ nearly).

27. **Combinations of Motions.**—Fasten knitting needle (20) in vice (19), and fasten a bright bead on top of needle. View bead by light of one candle or one distant window. Strike or pluck in one direction. The bead will appear a straight line of light. While it is vibrating hit it in a direction at right angles to its motion and it will describe a circle or ellipse. Touch one side of it near the vice with a stiff feather and the ellipse will open and shut. Clamp the rectangular rod (20) in the same way, and the figures obtained are parabolic, or 8-shaped. Touch one side with the feather and they vary.

28. A bright bead being fastened to one end of the spring (21) the other end is clamped at various distances in the vice, and various curves are traced out by the bead on the free end.

29. **Analysis of Vibrations by Sinuosities.**—Fasten the tuning-forks (7), which are a fork and its octave, in the vice (19), clamping them between two pieces of wood. Fasten with beeswax on to the two prongs on one side two little styles of quill cut to fine flexible points. Soak a little cotton wool in turpentine, put it on a stone and set fire to it. Hold a glass plate (22) over the flame till one side is covered with lamp-black. Set the two forks vibrating with the fiddle bow (22) and draw the smoked face of the glass across the styles, waved lines will be scratched on the glass; and the higher pitched fork produces twice as many waves in the same length as its lower octave fork.

30. **Transverse Vibrations of Strings (Wires).**—To show that the rate of vibration of a stretched string varies inversely as its length, other things being the same, fasten two similar iron wires to the wood-screws of the monochord (23). Pass the other ends over the brass pulleys and fasten equal weights to them, say 28 lbs.,

using the whole lengths of the wires from the fixed bridge to the pulleys. Pluck the wires in the middle, and the same notes will be given. Insert one bridge halfway between the one pulley and the bridge, the corresponding string gives the octave higher than the unshortened string. Insert bridge anywhere in the other string. Make one string half as long as the other, and the shorter string always gives the higher octave or twice as many vibrations in a second as the longer one.

31. To show that the number of vibrations varies with the square root of the stretching force or weight, fasten two weights over the pulleys and let one weight be four times as great as the other. The wire with the heavier weight gives the octave higher than the one with the lighter weight. And this is the case if the bridges are inserted anywhere, provided the two are at the same distance from the pulleys.

32. Combine results 31 and 32. That is, hang any two unequal weights from similar wires over the pulleys, and use the whole length of the more weighted wire; shift the bridge of the less weighted wire till the two give the same note. It is then found that if the wire A has the length l_1, and is stretched by the weight w_1, and the wire B has the length l_2, and is stretched by the weight w_2, then when there is unison,

$$\frac{\sqrt{w_1}}{l_1} = \frac{\sqrt{w_2}}{l_2} \text{ or } \frac{w_1}{l_1^2} = \frac{w_2}{l_2^2}.$$

Verify this by altering the length of A.

33. From the above equation find out the weight of a lump of iron which is fastened to one wire by obtaining unison on shifting either its bridge or that of the other wire, which is stretched by a known weight.

34. Show that, other things being the same, the number of vibrations varies inversely with the thickness

of the wire. Obtain the relative thicknesses of two iron wires by weighing equal lengths of them, and taking the square roots of their weights; vary the weights which stretch unequal lengths till there is unison. Then find that the square roots of the stretching forces or weights are inversely as the thicknesses. Or that therefore the stretching forces are as the squares of the thicknesses, *i.e.* as the weights of the wires. Take equal stretching forces and vary the lengths till there is unison. Then find that the lengths are inversely as the thicknesses. That is, verify the following: where n is the number of vibrations per second, l the length, s the stretching force, d the thickness of the wire, and w the weight of a given length.

$$n_1 \sim \frac{\sqrt{s_1}}{d_1}$$

$$n_2 \sim \frac{\sqrt{s_2}}{d_2}$$

or if there is unison so that $n_1 = n_2$

$$\frac{n_1}{n_2} = 1 = \frac{\sqrt{s_1}\, d_2}{\sqrt{s_2}\, d_1}$$

$$\text{or} \frac{\sqrt{s_2}}{d_2} = \frac{\sqrt{s_1}}{d_1}$$

$$\text{or} \frac{s_2}{d_2^2} = \frac{s_1}{d_1^2}$$

$$\text{or} \frac{s_2}{w_2} = \frac{s_1}{w_1}$$

35. To obtain the relative diameters of wires of dissimilar metals, weigh equal lengths and take the square roots of the weights and divide these numbers by the respective specific gravities of the metals. The specific gravity is got by dividing the weight of any piece of the

metal by the amount of weight it loses in water (that is by the weight of an equal volume of water).

36. The ordinary musical scale is as follows for any octave where n is the number of vibrations per second of the lowest note (tonic) :—

Tonic.	Second.	Major Third.	Fourth.	Fifth.	Major Sixth.	Major Seventh.	Octave.
n	$\frac{9}{8}n$	$\frac{5}{4}n$	$\frac{4}{3}n$	$\frac{3}{2}n$	$\frac{5}{3}n$	$\frac{15}{8}n$	$2n$

If the middle C is taken as having 256 vibrations a second, the eight complete notes from this C to its higher octave are—

C	D	E	F	G	A	B	C′
256	288	320	341·3	384	426·6	480	512

If the middle C is taken as 264 the numbers are—

C	D	E	F	G	A	B	C′
264	297	330	352	396	440	495	528

Divide the monochord (23) scale, whose length from the fixed bridge to the peg or pulleys is, say, l, into intervals of the lengths,

$$l, \quad \frac{8}{9}l, \quad \frac{4}{5}l, \quad \frac{3}{4}l, \quad \frac{2}{3}l, \quad \frac{3}{5}l, \quad \frac{8}{15}l, \quad \frac{1}{2}l$$

Then whatever be the stretching force, these lengths, when the moveable bridge is placed at the corresponding marks, form a scale. The full length may be tuned by turning the peg or weighting over the pulley till it is in unison with a known fork, say A.

37. **Nodes in Strings and Rods.**—Slightly stretch, and rigidly fasten in a vertical position, the two ends of an empty caoutchouc tube (1). Slightly pinch (damp) the middle and pluck the tube at a quarter from bottom; on taking away the damping fingers a node remains

there. Damp the tube at one-third and pluck at one-sixth from end, two nodes are formed, and so on.

38. Use the stretched monochord wire instead of the tube. Place paper riders at every one-eighth of the wire's length. Touch the second one with a stiff feather and gently pluck the wire where the first is. The third, fifth, and seventh will be thrown off, while the second, fourth, and sixth remain.

39. Fasten a tuning-fork (7) upright in a vice (19), tie a piece of cotton to the top of one prong, prevent its slipping by a little wax. Carry the thread over a smooth ring of wire and fasten a weighed cardboard tray to the other end. Let the two prongs of the fork and the thread be in one plane. Load the tray, and move the ring to and from the fork ; or, keeping the ring fixed, vary the weight till, when the fork is bowed, there is only one segment, that is, the thread swings as a whole. Keeping now the length the same, make the weight (reckoning the tray) only a quarter as great ; two segments are formed. If the weight be one-ninth as great, there will be three segments ; if one-sixteenth there will be four.

If the string be at right angles to the fork's two prongs the segments formed are always twice as numerous as in the former cases, if the lengths and weights are the same as before.

40. Hold deal rod (19) upright in hand, and by tilting the hand to and fro less or more rapidly, make one or more nodes. Mark the places of the nodes and measure the segments ; notice that the last division swings free, and is less than half a segment in length.

41. Cut (24) a strip of window glass about one inch wide and any length l (about six inches), and lay it across two parallel strings at such a distance apart that each string is a little less than a quarter l from the end. Fasten the strings to the glass with a little drop of wax in the

middle of the glass. On hitting the glass in its centre a note will be produced resulting from the formation of one segment of length rather more than $\frac{l}{2}$ in the middle and two free half segments each rather less than $\frac{l}{4}$. Referring to 26 for the number of vibrations of a rod, and to 36 for the relative numbers of vibration in the gamut—

$$\frac{n_1}{n_2} = \frac{l_2^2}{l_1^2}$$

In the gamut $n_2 = \frac{9}{8}n_1$, for the next whole note,

$$\therefore \frac{8}{9} = \frac{l_2^2}{l_1^2} \text{ or } l_2 = l_1\sqrt{\frac{8}{9}}.$$

Similarly for the next whole note—

$$l_3 = l_1\sqrt{\frac{4}{5}};$$

and so on.

Calculate these lengths and cut strips of glass accordingly. Support and fix them with wax in a row on two horizontal threads making an angle with one another. Compare the motion of such bars with that of the water in a rectangular trough (3) when the central line is elevated and depressed.

42. Hold fork (7) horizontally and bow it; scatter sand on it. All is thrown off. Bow it near the root. A shriller note is produced, and some of the sand rests in a line—a nodal line—somewhat less than $\frac{1}{3}$ of the fork's length from the end. Prove by monochord that the two notes are nearly as 1 : 9 (number of vibrations per second).

43. Remove clapper from hand bell (15); fix the bell vertically upside down in vice (19). Hold a pellet of sealing wax, the size of a pea, hung from a silk thread, against the edge of the bell. Bow the bell, and move the pellet round, finding the four nodal points and the four regions

of greatest motion. Nearly fill the bell with water and bow. Notice regions of comparative rest, and of disturbance. Move quickly in and out by the hands two opposite sides of an elastic wire (23) hoop. Notice nodes and segments.

44. **Beats.**—Clamp two similar tuning-forks (7) in vice (19) or screw them into board (11) or monochord (23). Load one near its root with a threepenny piece stuck on with wax. Bow both forks. Notice beats. Change threepenny for a sixpenny piece. The beats become more frequent. Move the coin higher up; the beats become still more frequent.

45. Determine rate of loaded fork with monochord (23), knowing that of unloaded. Show that the number of beats per second is equal to the difference between the numbers of vibrations per second of the two forks.

46. Increase the load on one fork till harshness or dissonance ensues. Again compare rates.

47. **Longitudinal Vibrations. Solids.**—Clamp between edges of wood in the vice (19) in the middle and horizontally the brass tube (25). Rub one end longitudinally with wash-leather (25) covered with powdered rosin (25). Hang a pellet of wax touching the other end. Observe how it is thrown off.

48. Let two glass tubes (25), one twice as long as the other, be held, each in the middle, between finger and thumb, and let one end of each be rubbed with wet flannel longitudinally. The longer tube produces the lower octave of the shorter one. A wave of compression has to travel twice as far from end to end and back in the former as in the latter case, and therefore takes twice as long; and accordingly in the same time it reappears and hits the air half as often. Prove this by stretching equally two pulley wires of the monochord and moving the bridges till the one wire is in unison with the

one tube, and the other with the other tube. The wires are then found to be in length in the ratio of 2 : 1.

49. Take equal lengths of deal and oak rods (25); hold them in the middle and rub ends with rosined leathers. The note from the oak is the deepest. Cut (26) pieces off the oak rod till the notes are in unison. Measure the lengths. The lengths are in the proportion of the rates of progression of the compression wave in the respective rods. Because the compression has to travel from one end to the other, and back again, in order to beat the air once to produce one sound wave.

50. To find the actual rate, tune, by cutting one of the rods, to a tuning-fork of known rate (No. of vibrations per second). This is best done by augmenting the sound of the fork by holding it over a resonant jar or cavity (see below 55). If the fork gives n vibrations to and fro in one second and the rod is in unison with it, the compression in the rod must travel from one end to the other and back (that is, twice the whole length of the rod) n times in 1 second. Assuming sound to travel in air 1,100 feet in 1 second, it travels in deal about 16,000 feet in a second.

51. Hold two similar wooden rods, one in the middle, and the other at a quarter its length from one end. Set both in longitudinal vibration, rubbing the shorter end of the second, octaves will be produced. The second rod will have a node at a quarter its length from the further end.

52. Wrap a piece of thin iron wire (23) tightly into a close spiral round the brass rod (25). Hang the spiral by one end, and hang a little weight at the other. Note with watch the number of jumps the wire gives in a few seconds when pulled out. Vary its length and the weight. Compare with half of longitudinally vibrating rod clamped in the middle.

53. Fasten rigidly both ends of the wire spiral of 52, slightly stretched and vertical. Set the middle moving up and down. Also damp the middle and pull the centre of the lower half gently down and release it. The middle forms a node. Obtain two automatic nodes in a similar manner.

54. **Tubes open and closed at one end.**—Fasten a piece of glass tubing (27) about 18 inches long vertically. Fit a cork into the bottom. Through the cork pass a narrow piece of glass tubing. Fasten one end of a piece of vulcanized caoutchouc tubing about three feet long (1) to this. To the other end of the elastic tubing attach the neck of a funnel (16). Support the funnel on the filter stand (27). Let the funnel be a little above the top of the tube. Fill both with water. Sound the highest ot the three forks (7). Hold it over the upright tube, depress the funnel till the fork's note is greatly augmented. Lift the funnel up and down, and fix it when the augmentation of the fork's note (resonance) is greatest. Mark the height of the water in the tube exactly. Cut the tube with a file (26) about $\frac{1}{4}$ inch below mark. Grind it down on a wet hearth-stone exactly to the mark. Cut and grind down several glass tubes of this same length. Make caps for the tubes by cutting round discs of card-board as large as the outside of the tubes, these discs can be stuck on to the ends of the tubes with beeswax.

55. Show that if a fork resounds with a tube closed at one end of length l, it will resound with a tube open at both ends of length $2l$. To show the latter, fasten two tubes together by an inch of india-rubber tubing (27).

56. Show that if a fork resounds with a tube of length l closed at one end it will resound with tubes closed at one end whose lengths are $3l$, $5l$, $7l$, etc.

57. Show that if a fork resounds with a tube open at

both ends of length l_1 it will resound with tubes open at both ends whose lengths are $2\ l_1$, $3\ l_1$, $4l_1$, etc.

58. Show, as far as the forks at disposal will allow, that if a fork resounds with a tube closed at one end, those forks will resound with the same tube whose notes are the next harmonic but one, the next but three, and so on, above that of the first fork.

59. Show that if a fork resounds with an open tube all forks will do so whose notes are higher harmonics of the first.

60. Admitting that for all notes—

$$\text{wave length in feet} = \frac{\text{number of feet traversed in } 1''}{\text{number of waves generated in } 1''},$$

and admitting that the resonant tube closed at one end is $\frac{1}{4}$ the wave length of the wave system of the lowest note which resounds in it, deduce (*a*) the rate of transmission of sound through air, knowing the number of vibrations of a fork and the length of the air column closed at one end or open at both, which resounds with it ; (*b*) deduce the wave-length, assuming the rate of propagation to be 1,100 feet a second, and knowing the pitch of the fork ; (*c*) deduce the pitch of the fork, knowing the rate of propagation and the length of the resonant column.

61. Heat a closed tube, which resounds with a given fork, over an air gas flame. Show that it no longer resounds. Invert the tube, and fill it with coal gas. It no longer resounds. Use apparatus in 54. Get the tube when containing air to resound to a fork ; fill it with carbonic acid (17) by displacement ; show that the column must be shortened to resound and compare lengths. This should verify the generalisation that when d is the density,

$$\text{rate} \propto \frac{1}{\sqrt{d}}.$$

62. **Effect of Relative Motion between Origin of Sound and Ear.**—Fasten a whistle (29) in one end of a

caoutchouc tube about 6 feet long. Sound the whistle by blowing into the other end. Whirl the tube round while continuing to blow, and notice the alteration of pitch at different places. This is best heard at a distance.

63. **Singing Flames.**—Draw out a piece of glass tubing till the opening at the end is about as wide as a pin. Fasten to gas pipe, place vertically, and light. Reduce the flame to the height of about $\frac{1}{8}$ to $\frac{1}{4}$ inch. Clamp over it a glass tube so that the flame is about a quarter of the tube's length up the tube. The air in the tube will give a note. Place a similar jet and tube side by side with the former one. Provide each tube with a little sliding tube of paper so as to be able to alter the lengths, obtain perfect unison, and various beats. Show that the singing of the flame immediately begins if the voice is pitched to the note which the flames would give. Also start by a consonant tuning-fork.

64. **Artificial Larynx.**—Grind off the top of a glass tube (27) in two planes at an angle of about 60°. Stretch across the top two pieces of vulcanized caoutchouc (29) in such a manner that there is a slight crack between them, bind the caoutchouc on to the tube with silk, and blow through.

APPARATUS AND MATERIALS FOR EXPERIMENTS IN SOUND AND WAVES.

(1) Three similar vulcanized caoutchouc tubes, each about $\frac{1}{4}$ inch wide and 12 feet long. One filled with sand and tied up at the ends. A piece of similar tubing 6 feet long.

(2) A long narrow wooden trough 4 feet × 6 inches × 6 inches caulked with marine glue, and painted inside. Preferably with one long face of glass. A block of wood $5\frac{3}{4}$ inches × 4 inches × 4 inches, with handle perpendicular from middle of one long face. Balls of wax mixed with iron filings so as just to float.

(3) Two cylindrical zinc troughs about 2 feet and 18 inches diameter, and 18 inches deep. A rectangular trough 2 feet × 1 foot × 18 inches. Silk thread, leaden bullets. A beaker with bottom about 3 inches diameter.

(4) A box about 18 inches cube, one side removed and replaced by sailcloth nailed tight on. The seams of the box made tight by paper pasted on the inside. A circular hole in the side of the box opposite to the canvas. The hole can be covered by a plain piece of cardboard. Two holes, side by side on one side of the box, into which pass glass tubes bent at right angles, the other ends of which pass through corks in the necks of two flasks, one containing ammonia and the other hydrochloric acid.

(5) Two air gas burners with tubes.

(6) Fasten a tin or glass tube, $\frac{1}{8}$ inch diameter, to the middle of a circular plate of tinplate or cardboard about 6 inches in diameter, with a hole in the middle in which the tube fits. A circular piece of cardboard somewhat less than the disc.

(7) A toy air-ball, the larger the better. Three tuning-forks, two alike and one an octave higher.

(8) A glass tube about $\frac{1}{4}$ inch internal diameter and 50 inches long, smoothly and as flatly as possible closed at one end. The tube is bent into two parallel limbs at a distance of about 10 inches from the closed end. It is fastened to an upright board upon which are ruled horizontal lines $\frac{1}{10}$ inch apart. Enough mercury to fill the tube.

(9) A stout glass tube about $\frac{1}{2}$ inch internal diameter and 6 inches long, closed at one end by a cork which is made air-tight by sealing-wax. A cylindrical wooden rod just passing into the tube, wrapped round at one end with silk thread, till it just fits the tube. The silk is oiled or covered with glycerine. A piece of German tinder. A little bisulphide of carbon.

(10) A dozen marbles or 'solitaire' balls.

(11) A deal rod, any shape, 12 feet long, covered with list, hung from threads or clamped horizontally. A square thin deal board, not cracked, about 2 feet square.

(12) A glass tube about 18 inches long and $\frac{1}{2}$ inch wide, closed at one end, is fastened perpendicularly by a little wax to the board (in 11), which is supported on three corks. The tuning-fork (7) has a little cone of cork fastened to one face of one prong by beeswax.

(13) Two tinned iron tubes, each about 3 feet long and 4 inches diameter; the end of one fits into the end of the other.

(14) A pointed deal rod, about 6 inches long, fastened to a square light deal board 5 inches square.

(15) A hand bell, the larger the better.

(16) A glass funnel about 4 inches in diameter. A cork to fit its neck. A clamp or support for the funnel. Carbonate of soda, tartaric acid.

(17) A 1 lb. flask, fitted with a cork through which

pass air-tight (a) a straight tube reaching to the bottom with a funnel at the top, (b) a tube bent at right angles, which just passes through the cork. Pieces of marble. Hydrochloric acid.

(18) A large humming-top with a smooth button driven into its peg. Filled with sand and closed. Resting upon the body of the top and fastened to it is a horizontal disc of thin iron plate, having 200 or 300 teeth in its circumference. Also two rings of holes near the circumference. One ring having twice as many holes as the other. A piece of quill glass tubing bent to 135° at one end.

(19) A deal rod, about 12 feet long, 1 inch wide, and $\frac{1}{2}$ inch thick. The ratio of width to thickness should be very exact. A table vice.

(20) A round knitting needle. Some hollow silvered glass beads. A square steel rod, about 8 inches long, and $\frac{1}{10}$ inch square. A rectangular steel rod, about 8 inches long; one side $\frac{1}{10}$ inch, the other $\frac{1}{20}$ inch. The ratio should be very exact.

(21) A straight piece of clock spring about 1 foot long is softened in the middle in the flame of an air-gas burner, and twisted so that the planes of the two parts are at right angles to one another.

(22) A fiddle bow. Some sheets of glass, 3 inches × 4 inches. Some oil of turpentine.

(23) *Monochord, etc.* An inch deal board, 3 feet long, 9 inches wide. Two pieces of wood, 6 inches × 1 inch × 1 inch, screwed on across ends to form supports. Three long wood screws driven in obliquely (slanting outwards) at one end at equal distances. At the other end, opposite one screw, is a pianoforte peg, at an angle of 45. Opposite the other two screws are two brass pulleys (window-blind pulleys) on stems which are driven in at an angle of 45°. A bridge, that is, a triangular wedge of hard wood,

9 inches long, $\frac{1}{4}$ inch wide at base, and as high as the pulleys. This is screwed from below across the board about 3 inches from the wooden screws. Three other little moveable bridges about 1 inch long, as high as the pulleys, are provided. A variety of weights and hooks. A pair of pliers. Several yards of iron wire (pianoforte wire) of different thicknesses. Brass wire, some of which has the same thickness as some of the iron wire. The ends of three pieces of wire are twisted into loops and passed over the screw heads. One of the other ends is passed through the pianoforte peg, which is then twisted round by the pliers. The other two have loops twisted in them, and passing over the pulleys carry weights. A sheet of paper is gummed to the board having lines at every inch, and thinner ones at every $\frac{1}{10}$th inch. Mark with 0 the line beneath the pulleys and at the pianoforte peg.

(24) A sheet of window glass. 2 square feet of patent plate glass. A glazier's diamond or steel wheel-glass-cutter.

(25) Several round deal and oak rods, 6 feet long, $\frac{1}{2}$ inch diameter. One brass rod or tube $\frac{1}{2}$ inch diameter, 3 feet long. Glass tube, $\frac{1}{4}$ inch diameter, 3 feet long. A square foot of flannel. A piece of wash-leather. Some powdered rosin.

(26) Small hand-saw. Small triangular file.

(27) Twelve feet stout glass tubing, $\frac{3}{4}$ inch internal diameter. A few inches of $\frac{1}{8}$ inch tubing. A filter stand and a retort stand. A few feet of vulcanized caoutchouc tubing, $\frac{1}{2}$ inch internal diameter.

(28) A dog whistle without the pea.

(29) A few square inches of thin vulcanized sheet caoutchouc.

INDEX.

The numbers refer to the paragraphs.

LONDON: PRINTED BY
SPOTTISWOODE AND CO., NEW-STREET SQUARE
AND PARLIAMENT STREET